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Modeling the risk factors associated with the neck disorders during manual material handling tasks

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MODELING THE RISK FACTORS ASSOCIATED WITH THE NECK DISORDERS DURING MANUAL MATERIAL HANDLING TASKS

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ABSTRACT

Work-related musculoskeletal disorders (MSD) of the neck or cervical spine result in longer sick leaves, substantial levels of human suffering, and high costs for society. Epidemiological studies clearly indicate strong associations between MSD of the neck and the work activities requiring forceful arm exertions and heavy lifting. However, studies evaluating the loading of the cervical spine during forceful arm exertions and heavy lifting tasks are limited. Major neck muscles, the sternocleidomastoid and the upper trapezius, run parallel to the cervical spine and couple the shoulder to the skull. It was hypothesized that such anatomical orientation may require these muscles to play an active role in supporting the shoulder during lifting activities and thus affecting the compressive forces acting on the cervical spine.

The loading of the cervical spine during a variety of manual material handling tasks was studied using electromyography (EMG) and biomechanical modeling techniques. In the EMG study, thirty healthy participants simulated isometric lifting, pushing, and pulling tasks at different heights (e.g., knuckle, elbow, shoulder, and overhead) exerting 25%, 50%, and 75% of their respective maximum static strengths in different neck postures (e.g., neutral, fully flexed, and fully extended neck postures). An increase in the weight significantly affected the activation of neck muscles ($P<0.001$). Independent of the weight lifted, the sternocleidomastoid showed the highest activation at the extended neck posture, while the upper trapezius showed the highest activation at the flexed neck posture ($P<0.001$). The activities of the neck muscles increased significantly with an increase in lifting height from elbow to shoulder to overhead ($P<0.001$).

A biomechanical model of the neck consisting of four bilateral pairs of muscles was formulated and a double optimization procedure was used to determine the forces generated by the neck muscles. The total compressive forces exerted by the four neck muscles at the C4-C5 level during isometric lifting task at elbow height were 72.6(19.4), 128.5(37.7), and 184.4(56.1) N, corresponding to the 25%, 50%, and 75% weight conditions.

The results of this study demonstrate that the neck muscles play an active role during lifting activities and may influence MSD development due to resulting physiological changes.

CHAPTER 1: INTRODUCTION

Work-related musculoskeletal disorders (MSD) are defined as injuries or disorders of the muscles, nerves, tendons, joints, cartilage, and spinal discs associated with exposure to risk factors in the workplaces. MSD are further classified under two categories: idiopathic and traumatic. Idiopathic injuries are mediated through mechanical degradation and cannot be attributed to a specific act or incident (such as physical degeneration). Traumatic injuries are associated with an incident or an action including overexertion, sudden imbalance, pulling apart, crushing, impact, slip and fall. The four major risk factors associated with MSD include genetic, morphological (related to the anatomical structure), psychosocial (related to work environment e.g. low social support), and biomechanical (Kumar, 2001). Although genetic and morphological factors play an important role in understanding the prevalence of MSD, psychosocial and biomechanical factors play a crucial role in determining the effective control strategies. Among the various biomechanical risk factors, exposures to maximal and submaximal repetitive exertions, static exertions, and postures for prolonged durations and vibratory activities are known to result in musculoskeletal disorders. These work-related factors are common in a wide range of industries, including office work, healthcare, manufacturing, agriculture, and various manual material handling occupations.

Work-related musculoskeletal disorders (MSD) of the neck, upper extremity, and low back are a major cause of lost workdays in the United States. Nearly one million people each year report taking time away from work to treat and recover from musculoskeletal pain in the upper extremities and low back (Bowman, 1999). The cost associated with lost workdays ranges from $13 to $20 billion annually (NIOSH, 2001).

Regardless of the actual dollar cost, the impact of work-related MSD is enormous in terms of health and economics. The non-fatal occupational muscle injuries such as sprain, strains, and tears have been primarily linked with work activities, such as lifting objects that are too heavy, working in the awkward position for an extended period of time, twisting, bending, falling and slipping (Waters, 2004). Among work-related MSD, incidents of neck pain as a cause of absenteeism are not as frequent as low-back pain, yet they contribute significantly to the morbidity in many working populations (Hales and Bernard, 1996). MSD of the neck or cervical spine result in longer sick leaves, constitute a substantial level of human suffering, and contribute significantly to morbidity among various working populations (Hales and Bernard, 1996).

Work-related MSD of the neck encompass a wide range of inflammatory and degenerative diseases and disorders (Buckle and Devereux, 2002). Many types of tissue in the cervical region can be sites of pain, including the neck muscles, intervertebral discs, the posterior longitudinal ligament, and the facet joints (Cailliet, 1981). The neck disorders associated with musculoskeletal pain (i.e., inflammatory types) include tension neck syndrome and trapezius myalgia and are common among the occupations requiring prolonged and repetitive submaximal exertions by the neck muscles, e.g., VDT workers, sewing machine operators, and dentists. On the other hand, the disorders associated with degenerative disc diseases mainly include disorders of the cervical spine and are associated with occupations involved in physically demanding work activities (Hagberg and Wegman, 1987), e.g., health care, construction work, farm work, and manual material handling.

Despite of having a high incidence rate among various occupational groups, cervical spine disorders currently remain largely unstudied, with only inferential hypotheses for their etiologies. The purpose of this research is to evaluate the biomechanical risk factors associated with the occupational neck and/or cervical spine disorders associated with forceful arm exertions. The risk factors associated with the neck or cervical spine disorders were evaluated by studying the electrical activities of the major neck muscles - the sternocleidomastoid and the upper trapezius - using electromyography (EMG) during a variety of manual materials handling tasks. In addition, a biomechanical model of the neck consisting of four bilateral pairs of muscles was formulated and a double optimization procedure was used to determine the forces generated by the internal neck muscles at C4-C5 level.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

In this chapter, studies evaluating work-related neck or cervical spine disorders are reviewed. The studies are classified in two sections: epidemiological studies and occupational studies. In the epidemiological studies section, findings of various review studies, as well as individual cross-sectional and longitudinal studies, are presented to understand the work-related causal factors associated with neck disorders. In the occupational studies section, the experimental studies performed in the laboratory, as well as in the actual work settings, are summarized. The purpose of the occupational studies section is to identify the various work-related activities previously studied and the approaches used for the scientific study of neck disorders.

2.2 Epidemiological Studies

The following section presents, various epidemiological studies that explore the work related risk factors associated with neck MSD for different occupational groups. While presenting these studies, emphasis is given to understand the relationship between neck disorders and heavy lifting tasks.

Walker-Bone and Cooper (2005) presented a review of existing epidemiological studies that evaluate soft tissue musculoskeletal disorders of neck and upper extremity among a wide range of occupations. The study includes epidemiological studies performed during 1998-2001, as listed in the Embase and Medline databases. The studies examining neck disorders are described as heterogeneous by the authors, due to the wide variety in both design and participating population. The neck disorders are found prominent among automobile assembly workers, factory workers, secretaries, poultry workers, scissor makers, sewing machine operators, healthcare employees, and grocery checkers. The results of the reviewed studies indicate that neck pain is associated with a sustained abnormal neck posture, forceful and/or repetitive arm exertions, poor workplace support from supervisors/colleagues, and high work demands on the workers.

Ariens et al. (2000) reviewed 22 cross-sectional studies, two prospective cohort studies, and one case-referent study to identify physical risk factors for neck pain. The authors reported moderate evidence for a correlation between the work-related forceful arm exertions and neck-shoulder pain, as well as a correlation between heavy lifting and neck–shoulder pain. Malchaire et al. (2001) reviewed fifty-seven cross-sectional and seven longitudinal studies to determine factors associated with musculoskeletal disorders of the neck and upper limbs. Sufficient evidence was found for a linkage between forceful arm exertions and the hand/ wrist and neck–shoulder disorders.

NIOSH (1997) performed a critical review of available epidemiologic studies that associate the MSD of the upper extremity and the lower back with exposure to physical factors at work. Over 40 epidemiologic studies were examined to understand the causal relationship between physical workplace factors and the neck/shoulder MSD. Substantial evidence for forceful exertions leading to the occurrence of neck/shoulder MSD was observed in the epidemiologic literature. The “forceful work” for the neck/shoulder was defined as work activities which involve forceful arm or hand movements that apply loads to the neck/shoulder area. The working populations studied included: assembly female workers making telephone exchanges (Aaraas, 1994), industrial plant workers (Bjelle et al., 1981), chocolate manufacturing female workers (Veiersted and Westgaard, 1994), machine operators and carpenters (Viikari-Juntura et al., 1994), and letter carriers

(Wells et al., 1983). Additionally, the time spent in physically heavy work during previous employment was also listed as a possible risk factor for the deterioration of health of the neck/shoulder area (Jonsson et al., 1988).

The general population was examined in some studies to understand the overall trends of MSD. Sim et al. (2006) studied the general population to estimate the prevalence and impact of work-related neck and upper limb pain. The data was collected during 2001–2002 using cross-sectional surveys among 10,000 adults in North Staffordshire, UK, using questionnaires. The primary outcome measure included presence or absence of neck and upper limb pain. Participants required to provide details of up to five recent jobs, and the level of exposure to six work activities involving the neck or upper limbs. Psychosocial measures included job control, demand, and support. The results of the study showed significant independent associations between neck and upper limb pain and repeated lifting of heavy objects, prolonged bending of the neck, and working with arms at/above shoulder height.

An analysis of the cases reported by the practicing rheumatologists (for the period of 1997–2001) and by the occupational physicians (for the period of 1996–2001) was performed by Chen et al, (2006) to evaluate the incidences and the suspected cause of the work-related musculoskeletal disorders in United Kingdom. The case data from approximately 330 rheumatologists and 800 occupational physicians was obtained. Rheumatologists reported an estimated 2599 cases/year, and occupational physicians reported 5278 cases/year for the studied period. Authors found clerical jobs, craft related jobs, and machine work to be associated with the highest risk for the upper limb MSD.

The neck problems (muscular pain and/or disc problem) were found to be associated with the keyboard work, heavy lifting, and gripping or holding of tools.

Workers compensation claims in Washington State were examined by Silverstein et al. (2002) to identify industries at high risk for work-related MSD of the neck, back, and upper extremity. Authors used prevention index values to differentiate between the industries and identified five industries at the highest risk: (1) trucking and courier services, (2) nursing, (3) masonry, (4) air transportation, and (5) residential construction. The workers in these industries are frequently involved in various activities requiring forceful arm exertions at knuckle, elbow and shoulder heights.

The data obtained from a 5-year follow-up questionnaire study of 1,895 employees in Denmark, between 18 and 59 years old was presented by Feveile et al. (2002). Authors investigated the combined effect of both physical and psychosocial exposure on the musculoskeletal symptoms in the neck/shoulder and wrist/hand regions. Among men, twisting or bending and social support at work predicted neck/shoulder symptoms. Additionally, development of these symptoms indicated an interacting association with between heavy lifting and sedentary work.

The risk factors for the neck and upper extremity disorders among 2500 Swedish men and women between the ages of 18 to 65 were examined by Fredriksson et al. (1999). Among the work-related factors, lifting heavy physical load (up to 60 kg for men or up to 40 kg for women) was quite common. Any participant reporting pain, aching, or stiffness in the neck was regarded as a case of neck disorder. The heavy physical load at work in combination with some non-work related factors, such as additional domestic work, and unsatisfactory leisure time was identified as the risk factor for neck disorder.

Among the various working populations, the health care workers-especially nurses, ambulance attendants, and home care professionals-have a high prevalence of work related neck MSD. The jobs of these professionals demand lifting heavy loads, work in awkward postures, and transfer of patients (Marras et al., 1999). A number of studies used survey questionnaires to identify the prevalence of neck disorders among these health care professionals. Lipscomb et al. (2004) sampled 2000 active, licensed, registered nurses from two US state registries. The authors stated that neck, shoulder, and back MSD were, respectively, 20%, 17%, and 29% prevalent among the studied population. Trinkoff et al. (2002) obtained data using mailed surveys from 1163 randomly selected nurses. The data showed that 45.8 % suffered from neck MSD, 35.1% from shoulder and 47.0% from back MSD, respectively. Smith et al. (2003) found an incidence rate of 46.6% and 27.9% for shoulder and neck MSD, respectively, among the sampled 305 Japanese female nurses (84% response rate).

A number of investigations determined the work factors associated with the neck disorders among the health care professionals. Trinkoff et al. (2003) used a cross sectional survey design to obtain neck, shoulder, and back MSD, physical demands, job characteristics, and health and well being data from 2000 active, US licensed, registered nurses. The authors found associations of activities such as “moving or lifting heavy loads,” “lifting or lowering patients/objects to/from the floor,” and “pushing/pulling heavy objects or people” with neck or shoulder MSD. Aasa et al. (2005) studied the relationship between the work related factors and their association to the neck-shoulder and low back disorder for male and female ambulance attendants. The ambulance work primarily involves patient transfer, requiring these professionals to engage in heavy lifting, pushing, and carrying activities. Among the 1500 Swedish ambulance personnel who participated in this cross sectional study, a significant association showed the neck-shoulder musculoskeletal disorders linked with working in awkward postures and handling of heavy objects. Brulin et al. (1998) studied MSD among the home care personnel and associations with the physical, physiological, work-related risk factors. In this cross sectional study, 361 randomly selected Swedish women completed a questionnaire. The results of this study identified lifting in an awkward position (e.g., extended arms) as a probable risk factor for shoulder/neck pain. The results also show strong association between the activities demanding standing in forward-bent and twisted postures and shoulder/neck pain.

The MSD among the farmers in Kansas state were investigated by Rosecrance et al. (2006) to evaluate the prevalence of causal factors associated with MSD. A self-administered questionnaire was used and 499 farmers, active members of a southeastern Kansas farming cooperative, participated in this evaluation. The questionnaires consisted of three parts: (1) participant's farming operation, (2) demographic data, and (3) health issues. The participation rate was 57.2%. The highest prevalence of work-related pain was reported for the lower back (37.5%), followed by the shoulders (25.9%), and neck (22.4%). Data analysis showed that neck pain was strongly associated with lifting and carrying of heavy materials.

Some studies evaluated manufacturing plant workers to understand the prevalence of work related MSD. Aublet-Cuvelier et al. (2006) performed a 3-year follow up study at a French household appliance assembly company. During the period of three consecutive years, 459 employees were clinically evaluated to understand the incidence of prominent upper limb musculoskeletal disorders. Among the four plants at the company, work activities at two plants required manual handling of heavy loads. An annual clinical evaluation asked employees about their pain and symptoms and then the doctors physically examined the pain or symptoms. The anatomical regions subjected to evaluation were the neck, shoulders, elbows, hands, and wrists. The diagnosis criteria for the neck included: neck cervicobrachialgia pain or stiffness in the neck and/or pain or paresthesias association with the head movements and/or restricted neck movement in at least one direction (rotation, flexion/extension). The results of the study revealed that upper limb musculoskeletal disorders have a high prevalence in all production departments. On an average, 21 % of the employees reported having neck MSD during the study period (2000-2002).

The work-related musculoskeletal problems among female workers in the semiconductor industry in peninsular Malaysia were studied by Chee and Rampal (2004), involving 18 factories with a participation rate of 75% with a cross sectional study. The data was collected from July 1999 to March 2000, using Nordic musculoskeletal questionnaires with some variations. The primary outcome variables were pain in the neck, shoulders, arms, hands/wrists, upper back, lower back, upper legs (hips, thighs, knees), and lower legs (ankles, feet) for the duration of one year or more. Exposures were measured in terms of the time spent during a workday climbing steps, lifting, standing, sitting, bending, twisting, pushing/pulling, and/or hand/wrist movements. The data was interpreted using logistic regression analysis. The neck/shoulder pain was found to be significantly associated with lifting activities and some other sedentary tasks. The lifting activities performed at the plants were mainly the lifting of the metal molding frames.

2.3 Summary of Epidemiological Studies

Epidemiological studies show a prevalence of neck MSD among a variety of occupational groups, showing a strong association between neck MSD and lifting of heavy objects and/or forceful arm exertions, static exertion over an extended period of time, repetitive arm exertions, and psychosocial stress. Based on the epidemiological evidence, several studies experimentally evaluated the work activities of various occupational groups, to understand the mechanism that could cause the neck MSD. In the following section, a number of biomechanical investigations, focused on the neck MSD for various occupational groups, are presented.

2.4 Neck Disorders - Occupational Studies

2.4.1 VDT Studies

The use of computers at work as well as during leisure time has increased worldwide in recent years. The various risk factors, such as repetitive activities and static posture, associated with the extensive use of computers, motivated several researchers to study the development of musculoskeletal symptoms caused by working with computers. In recent years, several studies have been performed to evaluate the effects of different aspects of the computer workstations, together with their effect on the role of the neck musculature.

VDT workstation designs were evaluated by Lu and Aghazadeh (1998) to understand probable risk factors associated with the general musculoskeletal and physical symptoms common among the VDT users. Based on the 88 VDT users studied, authors found that screen glare is an important risk factor, related to ocular symptoms. Workstation designs were significantly associated with awkward work postures, which were found to be an important risk factor of upper body symptoms. Different types of computer workstations offering variable levels of forearm support were examined by Delisle et al. (2006) to understand its impact on upper limb posture and muscle activation. Eighteen participants performed computer work for 20 minutes. It was found that the EMG amplitude of the upper trapezius and deltoid muscles was somewhat influenced by the workstations. The authors suggested that alternation between the workstations could solicit different muscles during computer work, and could be a possible strategy for preventing musculoskeletal disorders. Tepper et al. (2003) evaluated an ergonomic computer work station, characterized by an inclined working area and keyboard localization close to the screen, was evaluated by to study the activity of the upper trapezius muscle. Nineteen healthy subjects and nineteen patients with whiplash associated disorders performed a typing task for ten minutes at the new ergonomic and standard workstation. The data suggested no difference in muscle activity of the upper trapezius muscle between the two workstation and the two populations.

The placement of the monitor, especially its height from the floor and the viewing angle, as well as its effect on neck muscle activities, was also studied extensively in order to find a better placement of the monitor. The effects of the height of the video display terminal on working posture and electromyographic (EMG) activities of the neck and shoulder muscles was studied by the Villanueva et al. (1997) and Turville et al. (1998). The EMG of the neck muscle was related to the neck angles. A more flexed neck produced significantly higher neck extensor muscle activities. In contradiction to these findings, Kumar (1994) reported that a sunken monitor position resulted in 30% to 40% less EMG of the upper trapezius and sternocleidomastoid muscle, compared to a raised monitor. He studied three different monitor positions: (1) a monitor sunken and backward inclined by 35°, (2) a monitor placed on desktop level and horizontal, and (3) a monitor placed horizontal but raised by CPU beneath for a user with bifocal lens. Balci and Aghazadeh (1998) studied the influence of VDT monitor positions on performance and discomfort in the neck, shoulders, forearms, and wrists for users with or without bifocal lenses. The two monitor locations, placed 15º and 40 º below horizontal eye level, were evaluated. All the participants performed better and reported less discomfort in the neck with a 40 º monitor design. Users with bifocal lenses had significantly higher neck discomfort and lower performance than nonbifocal users. Bauer and Wittig (1998) investigated eleven different positions of screen and copy holders on the activities of cervical muscles and the subjective judgment given by the subjects. In agreement with Kumar (1994) and Balci and Aghazadeh (1998), the authors found that a screen position in which the vision axis is inclined slightly downwards was most preferred.

The different positions of the mouse within computer workstations were studied by Dennerlein and Johnson (2006) to evaluate biomechanical risk factors across different mouse positions. Thirty participants performed mouse-intensive tasks using a standard, central, and high mouse positions. The high mouse position produced the least neutral posture and resulted in the highest level of muscle activity. Little difference in muscle activity was observed between the remaining mouse positions. Chen and Leung (2007) studied the forearm and shoulder muscle activity in using different slanted computer mouse. Twelve participants performed same text-editing task with the five different slanted mouse. It was found that an increase in the slanted angle decreased the EMG activities of most of the studied muscles. The author concluded that an increase in the slanted angle of the mouse provides users more neutral hand positions by reducing the forearm and shoulder muscle activity and thus the risk of musculoskeletal disorders.

The typewriting task was evaluated by Kimura et al. (2007) to analyze the development and recovery of muscle fatigue in the upper trapezius muscle, using subjective and objective measurements. Six participants performed four sessions of typewriting tasks (25 minutes each). The EMG activities of the upper trapezius muscle were studied. The subjective fatigue and physiological muscle fatigue in the trapezius were reported to be in accordance with each other. However, individuals with subjective fatigue were found to recover more rapidly within the 1-h rest period, than with physiological fatigue. Fernström et al. (1994) studied the muscular activity of the upper trapezius with five other forearm and shoulder muscles during typewriting tasks using five different types of keyboard. The five different types of keyboards evaluated were: mechanical, electromechanical, electronic typewriter, personal computer/word processor (PC-XT) keyboard, and a personal computer keyboard angled at 20° to the horizontal plane. No difference in the strain on the neck-and-shoulder muscles was found among the five studied typewriters, except for the right shoulder muscle, which was more active using the electronic typewriter than with the other machines.

Different levels of work-rest schedule for the VDT users were evaluated as probable intervention strategies by Balci and Aghazadeh (2003). Three work-rest schedules (60-minute work/10-minute rest, 30-minute work/5-minute rest, and 15-minute work/micro breaks) were evaluated during data entry and mental arithmetic tasks.

Discomfort in the neck, lower back, and chest were minimal during the 15/micro schedule for the data entry task. For the mental arithmetic task, discomfort in the elbow and arm reflected the lowest discomfort with the 15/micro schedule. The overall performance, speed, and accuracy in tasks were highest during the 15/micro schedule, compared to the 60/10 and 30/ 5 schedules.

Blangsted et al. (2003) investigated quantitative job demands and the influence on muscular activity of shoulder and forearm muscles among women. The authors also analyzed gender differences for the duration of computer, mouse, and keyboard use and muscle activity of shoulder and forearm muscles during work. Twenty-four women and eleven men from a municipal administration participated in the study; data was collected in the occupational settings for one hour while the workers carried out their normal tasks. The results showed no association between self-reported quantitative job demands and the muscle activity patterns of the upper trapezius. No significant differences were seen in the EMG activities of women and men from the same department.

2.4.2 Light Assembly Work

Assembly workers' tasks demand repetitive arm movements and static neck postures for long durations. Bosch et al. (2007) studied fatigue and discomfort in the upper trapezius muscle during light manual work. The surface EMG data from two case studies were presented. The first case study was carried out in a production unit of a Dutch manufacturer of medical instruments while a second study considered a Dutch manufacturer of electric shavers. In the first case study of ten participants, the tasks involved assemblage of catheters by personally picking and placing small parts and then performing quality control by visual inspection. In the second case study of ten participants, the production-line workers carried out 18 movements / min to remove and then place small covers on automatically-painted shavers. The EMG activities of the upper trapezius muscle were studied to understand the objective estimates of muscle fatigue in the neck and shoulder region; and the subjective estimates were derived using the local perceived discomfort method. As the day progressed an increase in the EMG amplitude was found. The frequency analysis revealed an increase in the lower frequency power accompanied by a decrease in higher frequency. No clear relationship between perceived discomfort and objective indicators was observed.

The effect of work pace and break allowance on the assembly tasks were evaluated by Mathiassen and Winkel (1996) by measuring the EMG of the upper trapezius muscle. The work pace found to affect the EMG activities, reducing it with a decrease in the pace. Added breaks however, had no apparent effect on the upper trapezius EMG. Moller et al. (2004) studied the exposure similarity within and between the individuals performing electronics assembly work. The similarity was assessed for the level, frequency, and duration of muscle activity, as well as for working postures. This study also evaluated an increase in the variability, associated with a 'job enlargement' scenario. The study was conducted at a plant producing different automotive electronic components, selecting three workstations where a series of screw driving, soldering, and assembling work was performed. Two male and three female operators participated in the study. EMG was measured bilaterally from the descending part of the upper trapezius muscle and from the forearm extensor muscles; further, each operator was video recorded for the entire working day. The EMG parameters of upper trapezius showed a greater difference in mean exposure between workstations, compared to the forearm extensors.

The authors concluded that the effect of the job enlargement on exposure variability was more pronounced for the upper trapezius muscle than for the forearm extensor muscles.

2.4.3 Cash Register Users

The cash register operators were also found to experience incidences of neck and shoulder disorders, mainly due to high speed repetitive arm work and working with a flexed and/or abducted shoulder. Lannersten and Harms-Ringdahl (1990) studied the EMG activities of trapezius, infraspinatus and thoracic erector spinae muscles at sitting and standing postures as the cash register operators used four different types of cash registers, i.e., conventional with keyboard operation, horizontal scanner, vertical scanner, and pen reader registers. Work with the scanners and the pen reader generated higher loads on most of the studied muscles than conventional keyboard operation. Takala and Viikari-Juntura (1991) investigated the EMG of the upper trapezius and rhomboideus/erector spinae muscles of bank female cashiers with frequent neck-shoulder pain (cases) and ten non-symptomatic referents. Each participant performed a routine tasks. The mean EMG activities were found similar in both groups. Decreasing the height of the service counter by 25 cm reduced the mean EMG activation levels in the right upper trapezius in both cases and referents. Sandsjö et al. (2000) compared 18 supermarket female employees reporting neck and shoulder pain with 6 of their asymptomatic female colleagues when doing cash-register work. The EMG activity of the upper trapezius muscle of the symptomatic subjects showed a lack of low and high levels. Among the asymptomatic subjects the upper trapezius muscle was at rest for a longer duration. Lundberg et al. (1999) studied the psychophysiological stress responses, muscle tension, and neck and shoulder pain among 72 supermarket female cashiers. Fifty cashiers (70%) suffering from neck-shoulder pain (trapezius myalgia) were found to have a higher EMG activity at work and reported more tension after work. The stress levels were also found to be significantly higher at work, as reflected in the catecholamine, blood pressure, heart rate, EMG activity, and self-report.

2.4.4 Varied Occupational Tasks

Dental professionals are at a high risk of musculoskeletal disorders of the neck, shoulders, and hips (Åkesson et al., 1997). Finsen et al. (1998) studied the risk factors in dentistry which may contribute to musculoskeletal disorders. Three of the most common work tasks were studied by evaluating EMG activity levels of splenius and upper trapezius muscles. All of these studied tasks showed high muscle activity levels. Milerad et al. (1991) studied the muscular load levels in the neck, shoulder, and arm muscles. The authors concluded that dentistry work generates a relatively high muscular load on both trapezius and dominant extensor-carpi-radialis, and a relatively low load on the infraspinatus muscle. Pitts et al. (2005) conducted a survey among 100 practicing dentists and evaluated ten among them, biomechanically using EMG. Fifty-eight percent of the respondents reported that they experienced or had experienced some form of pain in the neck, shoulder, and lower back during their tenures as practicing dentists. The EMG of the upper trapezius muscle showed that the median frequency decreased significantly during both four and eight hours of work, indicating that the muscles were getting fatigued.

Sewing machine operators have also shown a high prevalence of neck and shoulder disorders. Jensen et al. (1993) studied EMG activities of the upper trapezius muscle of 29 industrial sewing-machine female operators during an 8-h working day under routine working conditions. The authors found a specific EMG signal pattern during sewing-machine work. These reserachers concluded that industrial sewing-machine work involves a pattern of shoulder muscle activity, which induces fatigue in the shoulder and neck regions. Lindberg et al. (1993) studied upper trapezius muscle activities for manual vs. automated fabric-seaming tasks. The EMG amplitude analysis revealed a higher risk of MSD for the manual seaming than the automated seaming tasks.

Veiersted et al. (1990) studied the pattern of muscle activity during stereotyped and machine-paced work tasks at a packing machine. Ten trained female workers participated in the study; the EMG activity of upper trapezius muscle was obtained. The researchers observed static muscle activity of 1.6% of maximal voluntary contraction. Workers with a previous occurrence of neck-shoulder pain were found to have higher levels of static muscle activity, with a considerable variability of muscle activity pattern between the subjects despite similar stereotyped work.

Anton et al. (2005) studied the construction workers in a laboratory setting to evaluate the effect of two different types of concrete blocks (light weight and standard weight) on the EMG activities of neck, forearm, and back muscles; and the energy expenditure was measured by heart rate. The authors also evaluated EMG activity associated with laying the concrete blocks as a function of course (row) height. Twenty-one masons participated in the study. Each of them constructed two 32-block walls, seven rows high, using light weight and standard weight concrete blocks. The upper trapezius muscle activity was not affected by the block weight. Substantially greater EMG activity was found for the bilateral upper trapezius at a height of 7th row compared to the 1st and 3rd row.

Jiang et al. (2006) studied the upper extremity muscle EMG activities and the upper body kinematics during a forearm supination task. Authors intended to study age related changes in the muscle recruitment and work technique (postural/kinematic), hence subjects from two different age groups were recruited. A total of twenty subjects participated in the study, ten in the age group 19–29 and ten in the age group 55–65. The participants performed a series of static and dynamic forearm supination tasks on a work simulator. These exertions were performed at eight different levels of supination torque: 5–40 lb-in in 5 lb-in increments. During the static exertion tasks, the EMG activities of upper extremity muscles were recorded, and during dynamic exertions, the motions of the upper body and upper extremity were captured. The supination torque level was found to affect the muscle activity and kinematics for both the static and dynamic exertions. The trapezius muscle showed 135% more activity among the older subjects than younger subjects during static exertions.

2.5 Summary of Occupational Studies

A variety of occupations and/or work activities have been studied experimentally to understand the causal factors associated with the neck pathologies. Mostly EMG of the neck muscles was used to understand the contribution of the neck muscles, which then were interpreted to understand the underlying mechanism of neck MSD. In the investigations presented above, the EMG of the neck muscles was found to show a characteristic association with the different work activities; however, work activities studied so far mainly include repetitive arm exertions with little or no forceful arm exertions and exertions requiring prolong static neck postures. None of the existing experimental studies has evaluated the activities of the neck muscles during work activities requiring forceful arm exertions or heavy lifting tasks.

CHAPTER 3: RATIONALE

Work related MSD are among the most costly health problems facing industries today. MSD of the neck or cervical spine accounts for nearly 30% of all chronic pain syndromes and contribute significantly to morbidity among various working populations. Substantial epidemiological evidence persists, suggesting a clear association of neck or cervical spine disorders with work activities requiring forceful arm exertions and heavy lifting tasks. However, most of the existing experimental studies that evaluate work-related neck or cervical spine disorders focus on the work activities, which require repetitive forceful exertions with little or no forceful exertion (VDT users, light assembly workers, cash register users) and prolonged static neck postures (sewing machine operators, dentists). Despite of having sufficient epidemiological evidence associating forceful or heavy lifting tasks with neck or cervical spine disorders, no previous experimental study has evaluated the role of neck muscles during lifting tasks.

Among neck disorders, heavy or forceful exertions are associated with the disorders of the cervical-disc complex, which are significant pathologies and constitute substantial pain and disability (Cailliet, 1981; Borenstein et al., 1998). The common cervical-disc complex pathologies are degenerative disc diseases, e.g., disc herniation, cervical spondylosis, osteoporosis, and cervical myelopathy. These pathological conditions involve impingement of nerves and spinal cord passing through the cervical spine, creating various clinical syndromes characterized by neck pain or numbness down the arms and in the fingers (Jeffreys, 1993; Bland, 1995). The excessive compressive forces acting on the cervical spine could be a possible pathway for producing degenerative disc diseases.

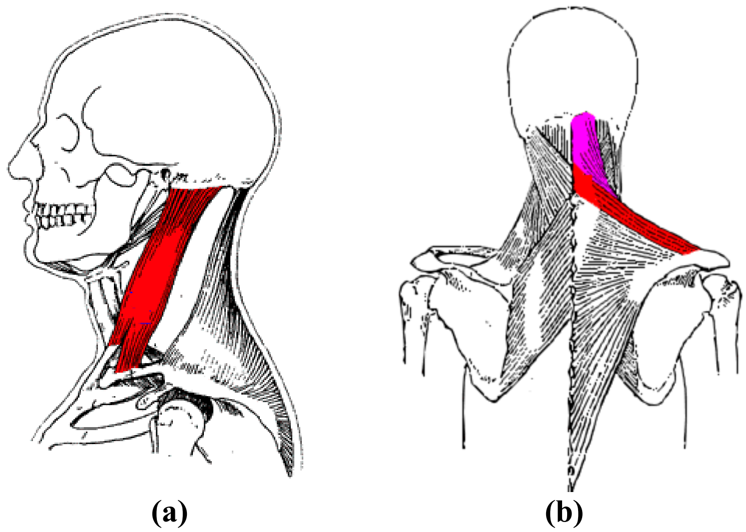


Figure 1: The anatomical arrangement of (a) sternocleidomastoid and (b) upper trapezius muscles.

A complex system of ligaments, tendons, and muscles surrounding the cervical spine supports the head and enables its diverse movements. The cervical bones - the vertebrae - are smaller in size than those in the thoracic and lumbar spine and possess higher mobility but lower weight bearing capacity (Sherk et al., 1988). Sternocleidomastoid and upper trapezius are the two major neck muscles (Figure 1). The sternocleidomastoid originates at the sternum (sterno-) and clavicle (cleido-) heads, passes obliquely across the side of the neck, and inserts at the mastoid process of the temporal bone of the skull (Figure 1 a). The upper or cervical trapezius muscle originates in the external occipital protuberance, medial 1/3 of the superior nuchal line, ligamentum nuchae and spinous process of 7th cervical vertebra and inserts into the lateral 1/3 of the clavicle and acromion process (Figure 1 b). Thus, the sternocleidomastoid and upper or cervical trapezius muscles run parallel to the cervical spine, coupling the shoulder to the skull. Such an anatomical orientation of these muscles may require them to support the shoulder during forceful arm exertions. If these muscles contract corresponding to the forceful arm exertions, then due to their anatomical arrangement, i.e., parallel to the cervical spine, these forces may affect the cervical spine compressive forces.

Thus, based on epidemiological evidence and considering the mechanical structure of the cervical spine, the purpose of this study is to evaluate the physical risk factors associated with neck or cervical spine disorders.

CHAPTER 4: OBJECTIVES AND RESEARCH HYPOTHESES

The aim of this study, evaluation of the physical risk factors associated with the neck or cervical spine disorders, was achieved by setting up two main objectives:

Objective 1: Evaluation of the electrical activities of the major neck muscles, the sternocleidomastoid and the upper trapezius, using electromyography

Objective 2: Calculation of the internal forces generated by the neck muscles by developing a biomechanical model of the neck at the C4-C5 level.

4.1 Objective 1

Objective 1 was achieved by studying a variety of manual material-handling tasks by simulating them in the laboratory setting. The tasks were designed based on the following criterions:

1) The tasks should represent the material-handling activities that are common at various workplaces.
2) Different levels of loads are exerted on shoulder joints during the tasks (progressively higher weights, different moment arm of the loads).
3) The forces are exerted in different directions (lifting, pushing, and pulling).
4) The forces are exerted at different lengths of the neck muscles (neutral, flexed, and extended neck postures).

Six different tasks were evaluated:

Task 1: Isometric lifting at elbow height, lifting 25%, 50% and 75% of the maximum elbow height static strength with the neck in neutral, fully flexed, and fully extended positions.

Task 2: Isometric lifting at shoulder height, lifting 25%, 50% and 75% of the maximum shoulder height static strength with the neck in neutral, fully flexed, and fully extended positions.

Task 3: Isometric lifting at overhead height, lifting 25%, 50% and 75% of the maximum overhead height static strength with the neck in neutral, fully flexed, and fully extended positions.

Task 4: Isometric lifting at knuckle and shoulder heights, lifting 25%, 50% and 75% of the maximum knuckle height static strength with the neck in neutral position.

Task 5: Pushing and pulling at shoulder height, exerting 25%, 50% and 75% of the respective maximum shoulder height, pushing-pulling strength with the neck in neutral position.

Task 6: Overhead pulling exerting 25%, 50% and 75% of the maximum overhead pulling strength with the neck in neutral position.

4.2 Objective 2

A biomechanical model of the neck, consisting of four bilateral pairs of muscles, was formulated. Based on the requirement that the body segments above and below a transverse cutting plane at C4-C5 levels remains in the equilibrium during the isometric lifting task at elbow height, a double optimization procedure was used to determine the forces generated by the neck muscles. This procedure involves formulating and solving two linear programming problems simultaneously. In the first problem, the muscle contraction intensity was minimized, and during the second problem, the summation of the muscle forces was minimized, using the muscle contraction intensity determined during the first problem.

4.3 Research Hypotheses

The role played by the neck muscles during isometric lifting, pushing, and pulling tasks was evaluated by testing six hypotheses (Figure 2). The hypothesis statements are as follows:

4.3.1 General Hypothesis 1

A consistent muscle activity pattern would be observed for the neck muscles for all the participants during the forceful arm exertions (i.e., during all tasks).

4.3.2 General Hypothesis 2

The muscle activity of the neck muscles would increase, corresponding to the increase in the lifting weights or forces exerted.

4.3.3 Task Specific Hypothesis 1

The anterior neck muscle (sternocleidomastoid) would show higher EMG activities at extended neck position, compared to the neutral and flexed neck positions, and the posterior neck muscle (upper trapezius) would show higher EMG activities at flexed neck position, compared to the neutral and extended neck positions. The muscle activity data collected during tasks 1, 2, and 3 was used to test this hypothesis.

4.3.4 Task Specific Hypothesis 2

The activities of the neck muscles would increase with the increase in the lifting heights from knuckle to elbow to shoulder. The muscle activity data collected during tasks 1, 2, 3, and 4 was used to test this hypothesis.

4.3.5 Task Specific Hypothesis 3

The activities of the neck muscles would be higher during lifting compared to pushing and pulling.The muscle activity data collected during tasks 2, 3, 5 and 6 was used to test this hypothesis.

4.3.6 Task Specific Hypothesis 4

The activities of the neck muscles would be higher during pulling, compared to pushing. The muscle activity data collected during tasks 5 and 6 were used to test this hypothesis.

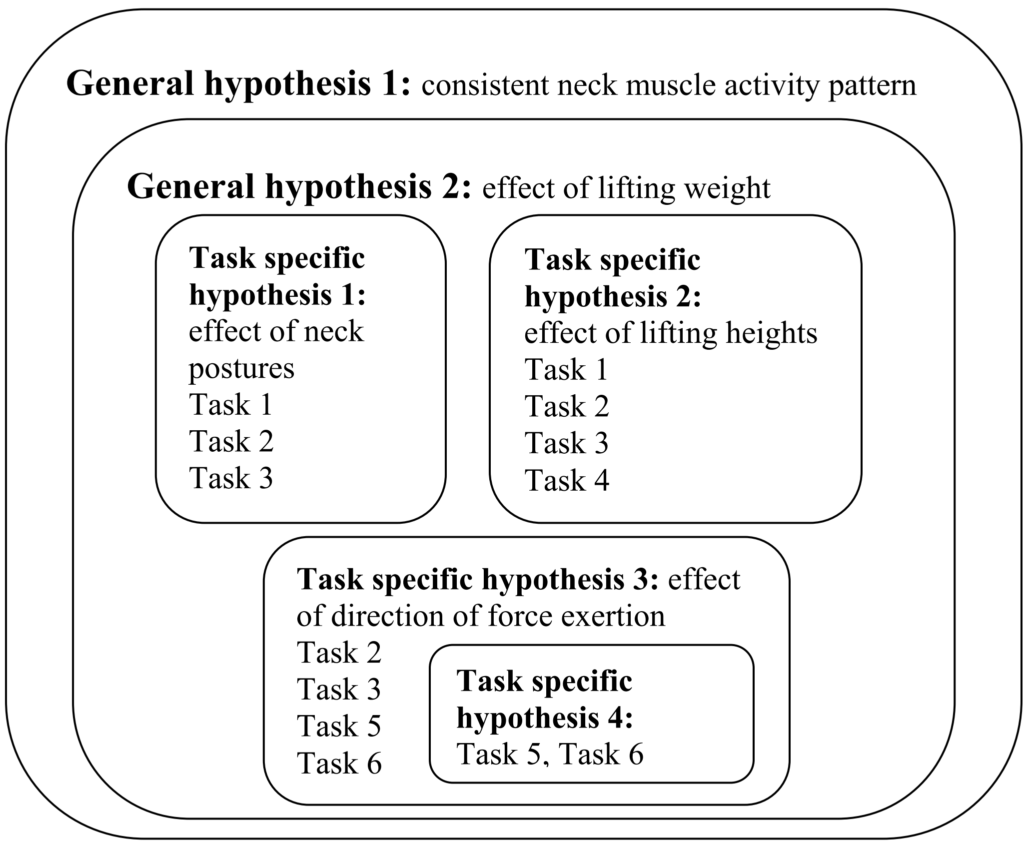


Figure 2: Schematic representation of the research hypothesis

CHAPTER 5: METHODS AND PROCEDURES

5.1 Introduction

The physical risk factors associated with the neck or cervical spine disorders were evaluated by conducting an EMG study and using biomechanical modeling techniques (Figure 3). In the EMG study, various manual material handling activities were examined by simulating isometric lifting, pushing, pulling tasks at various heights. The activities of the neck muscles were evaluated by using electromyography (EMG). In the biomechanical modeling part, a biomechanical model of the neck at C4-C5 level was developed and this model was used to calculate the internal forces generated by the neck muscles.

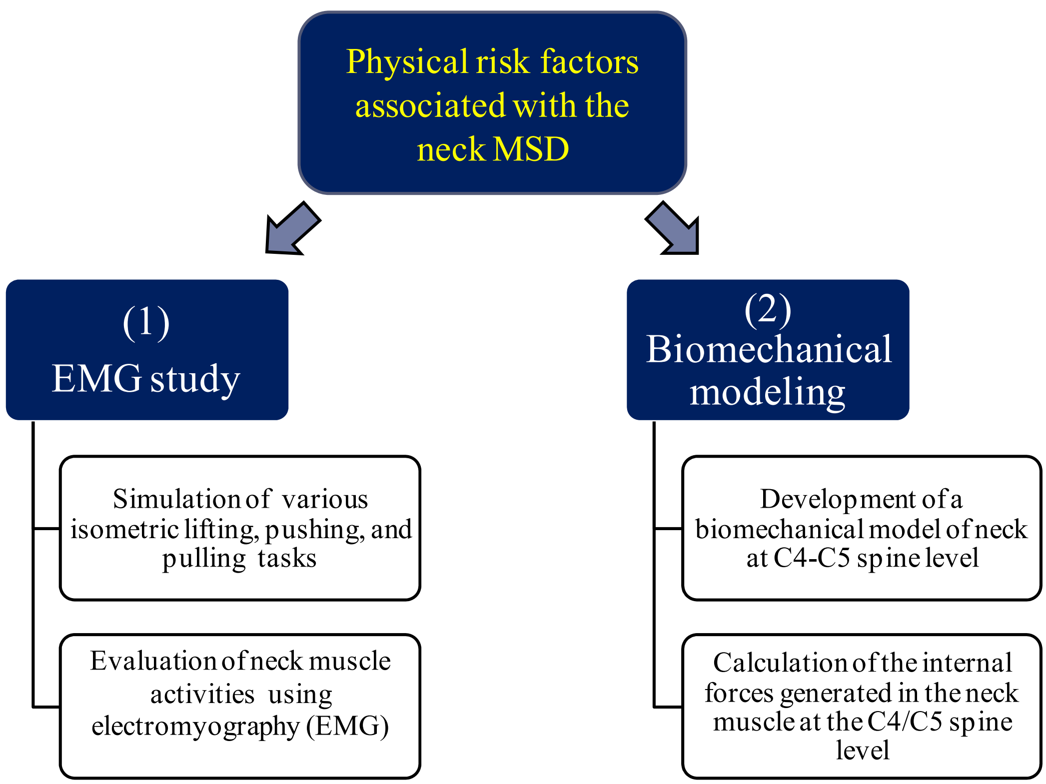


Figure 3: Schematic representation of the methods used to study the physical risk factors associated with the neck or cervical spine disorders

The details of the biomechanical modeling procedure are presented in Chapter 6. In this chapter, the specifics of EMG study, i.e., tasks evaluated, data collection and processing procedure, and statistical analysis are presented. Six different tasks were evaluated.

5.2 Participants

Thirty healthy participants (15 males and 15 females) with no history of musculoskeletal abnormalities participated in this study (power of the statistics 0.9515, Appendix A). The participants were graduate or undergraduate students at Louisiana State University. The Physical Activity Readiness Questionnaire (PAR-Q, British Columbia Ministry of Health) was used to screen participants for cardiac and other health problems (e.g., dizziness, chest pain, heart trouble) (Appendix B). Participants who answered yes to any of the questions on the PAR-Q were excluded. Prior to the data collection, the experimental procedures and the demands of the testing were explained to the participants, and their signature was obtained on the informed consent form approved by the Institutional Review Board at Louisiana State University (Appendix C).

5.3 Equipment

The equipment used for the data collection included (1) an electromyography (EMG) system, (2) isometric strength testing equipment, and (3) boxes and metal pieces of various masses.

5.3.1 Electromyography (EMG) System

Electromyography (EMG) is the study of the muscle function through the analysis of the electrical signal generated during muscular contractions (Acierno et al., 1995). An EMG signal is collected from the contracting muscle using an electrode. The electrode is the site of connection between the body and the data collection system. Based on the type of contact with the body, the electrodes are of two types: (1) non-invasive (surface electrodes) and; (2) invasive (wire and needle electrodes). The surface electrodes are employed when collecting data from the superficial muscles by simply adhering the electrode to the skin. The wire and needle electrodes are mostly used while collecting an EMG signal from the deep muscles, by inserting the electrodes through the skin. In the literature, the EMG involving use of a surface electrode is commonly referred to as surface electromyography. EMG techniques have been extensively used to study the patterns of activation or tension developed in the muscles during a variety of occupational tasks (Sommerich et al., 2000).

In this study, the EMG data was acquired using an eight-channel, wireless EMG system (Delsys Inc., Boston, USA). The system consists of an input module and Myomonitor V (Figure 4). The input modules host the EMG and the reference electrodes and transmit the signal to the Myomonitor IV. Myomonitor IV records the EMG signal, either as a wireless transmitter or an autonomous datalogger. In the wireless transmitter mode, the EMG data is transmitted over a wireless local area network (WLAN) to the host computer for real-time display and storage. In the datalogging mode, the EMG data is stored on the removable SD memory card (1GB standard), built into the Myomonitor V. The data was collected using the Myomonitor IV in the wireless transmitter mode.

The surface electrodes used were parallel bar, active surface electrodes (DE-2.3 EMG Sensors, Delsys Inc., Boston, USA) (Figure 5). The surface electrodes were single differential, i.e., the captured EMG signal is the result of the potential difference between V1 and V2 on the skin surface. The sensor contacts are made from 99.9% pure silver bars, measuring 10mm in length, 1mm in diameter and spaced 10mm apart.

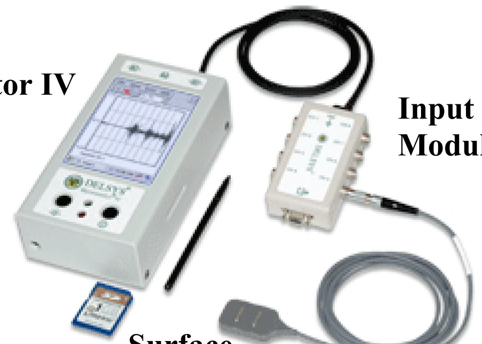
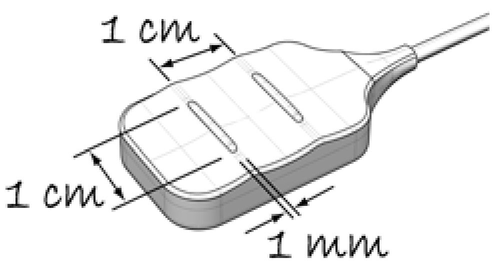
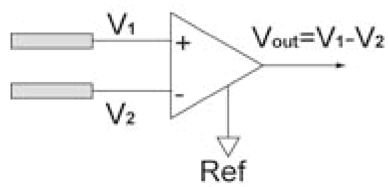


Figure 4: Eight channel wireless EMG system





(a) **(b)**

Figure 5: (a) Parallel bar active surface electrode used for the data collection; (b) schematic representing the captured surface EMG signal (Vout) which is the result of the potential difference between V1 and V2 on the skin surface.

5.3.2 Isometric Strength Testing Equipment

The maximum static strength during various isometric lifting, pushing, and pulling exertions at various heights was determined using isometric strength testing equipment (Prototype Design and Fabrication Company, Ann Arbor, MI, USA). The equipment consists of a horizontal lever arm (C) and a vertical post (D) (Figure 6). A load cell (B) is mounted on a horizontal lever arm. The horizontal lever arm is assembled on a vertical post, such that it could be moved along the vertical post and clamped at any desired height. The orientation of the load cell (B) and thus of the handle (A) could be adjusted to measure strength in different planes (lifting, pushing, pulling). The output of the load cell is recorded using force monitoring equipment (ST-1, Prototype Design Fabrication Company, Michigan, USA). This equipment is capable of recording instantaneous, peak, and average forces during exertions.

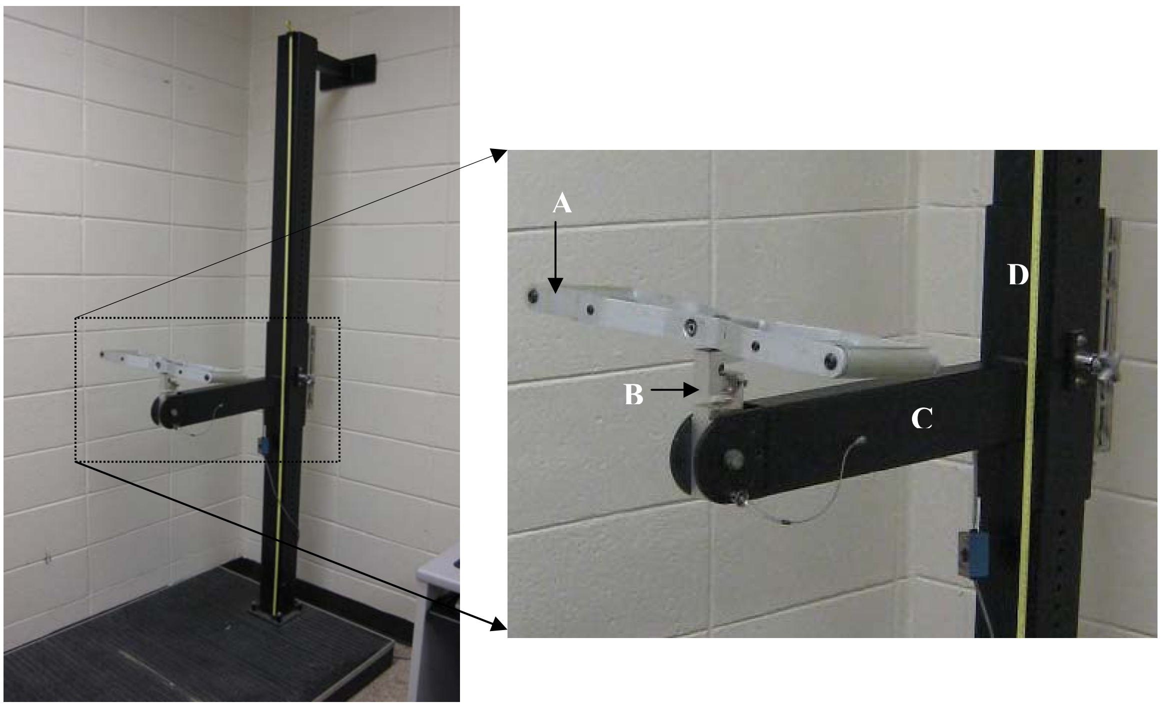


Figure 6: Isometric strength testing equipment; (A) handle, (B) load cell, (C) horizontal lever arm, (D) vertical post.

5.3.3 Boxes and Metal Pieces of Various Masses

The isometric lifting tasks were simulated by the participants by lifting and holding boxes of two different dimensions. The two boxes used were 30 cm wide (30 cm × 30 cm × 20 cm) and 42 cm wide (25 cm × 42 cm × 20 cm). To avoid excessive axial rotation of the upper arm, participants with a shoulder width of less than 35 cm simulated the lifting tasks using the 30 cm wide box, while the participants with a shoulder width more than 35 cm used the 42 cm wide box. The weight of the box was adjusted to a predetermined weight, using metal pieces of various masses.

5.4 Forceful Arm Exertion Tasks

5.4.1 Task 1: Static Lifting at Elbow Height

Lifting and holding tasks at elbow height is one of the more common work activities at various work places, e.g., construction or patient care. Many times, workers tend to perform such lifting and holding tasks at extended and flexed neck postures, because of necessary visual focal points (e.g., carrying objects up or down stairs and on ladders, holding materials while standing on inclined surfaces). This task was designed to simulate lifting activities at elbow height. During the actual lifting task at elbow height, the participant stood in the normal upright standing posture with her/his feet placed parallel and shoulder width apart. The participant lifted a box with cutout handles on each side such that the shoulder joint was approximately 0° abducted and 0° flexed and elbow joint 90° flexed and 0° supinated. The wrist was approximately 35°-45° ulnarly deviated to facilitate firm coupling with the wooden box. The lifting tasks were carried out at three different neck postures, i.e., neutral, fully flexed, and fully extended (Figure 7).

5.4.2 Task 2: Static Lifting at Shoulder Height

This task was designed to test a common, yet strenuous, work activity common at various work places. Lifting at shoulder height is considered very strenuous, due to a comparatively larger moment arm for the shoulder joint. The joint configuration during the lifting at the shoulder height involved approximately 0° abduction and 80°-90° flexion at the shoulder joint, 15°-20° of flexion and 0° supination at elbow height, and

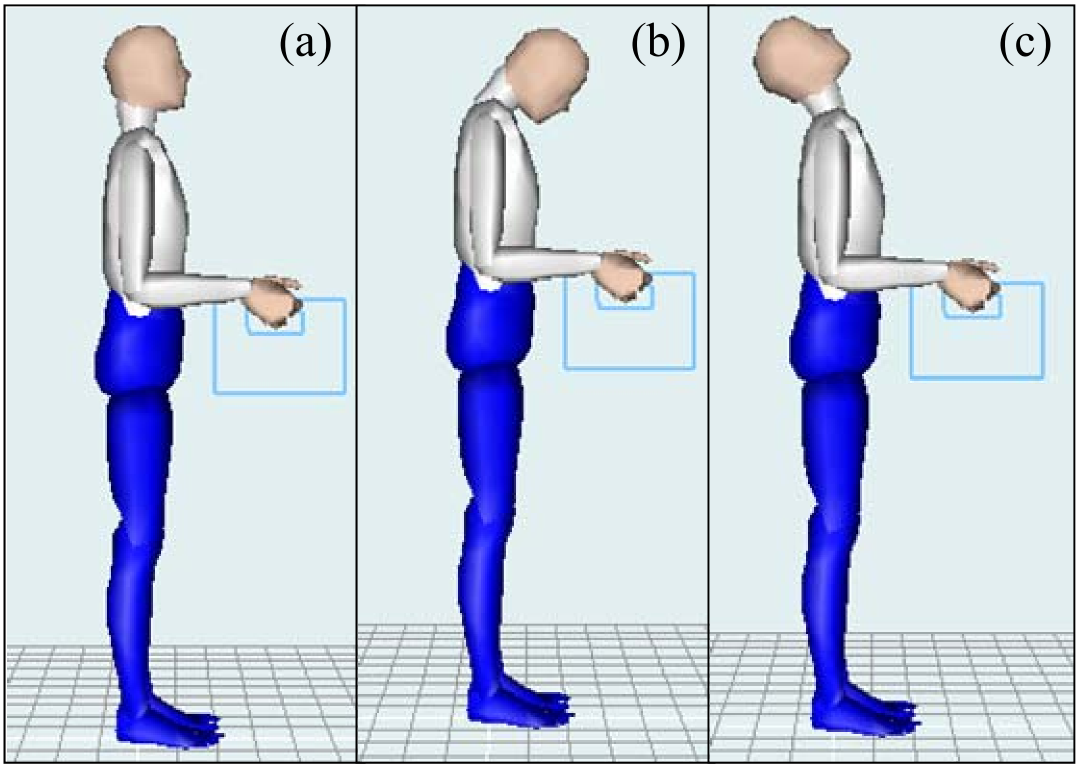


Figure 7: Task 1, lifting at the elbow height with neck in (a) neutral, (b) fully flexed, and (c) fully extended postures.

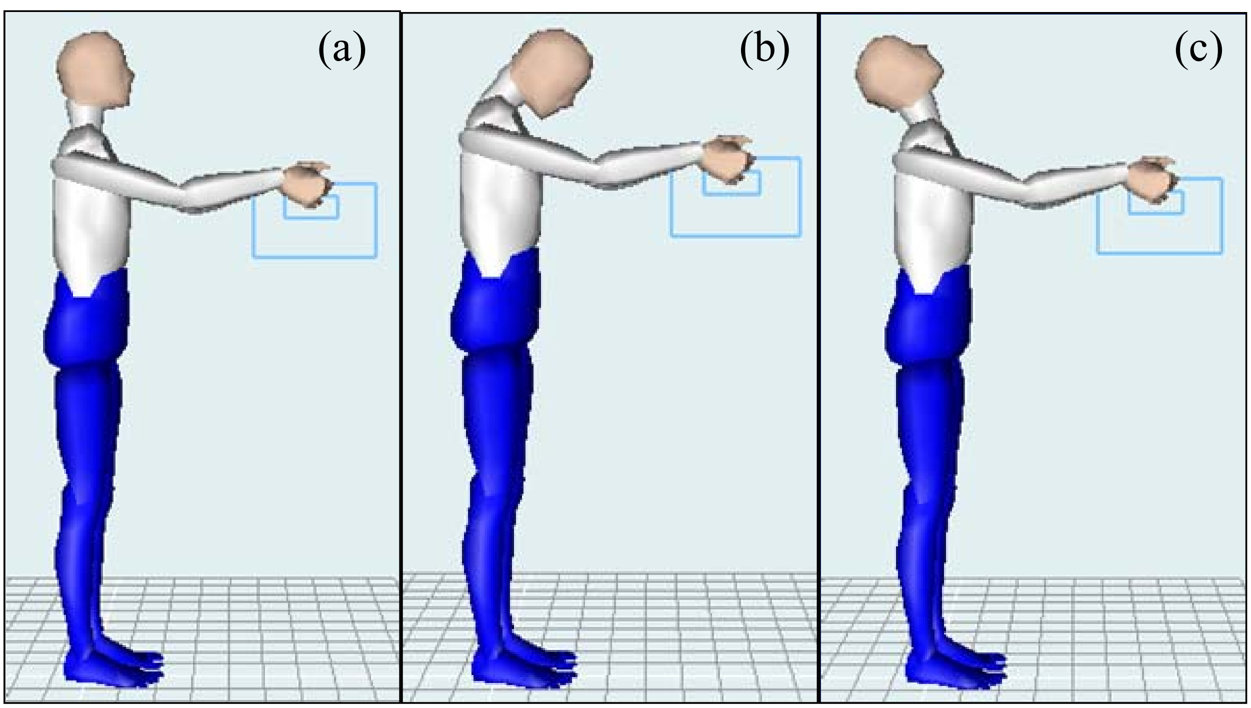


Figure 8: Task 2, lifting at the shoulder height with neck in (a) neutral, (b) fully flexed, and (c) fully extended postures.

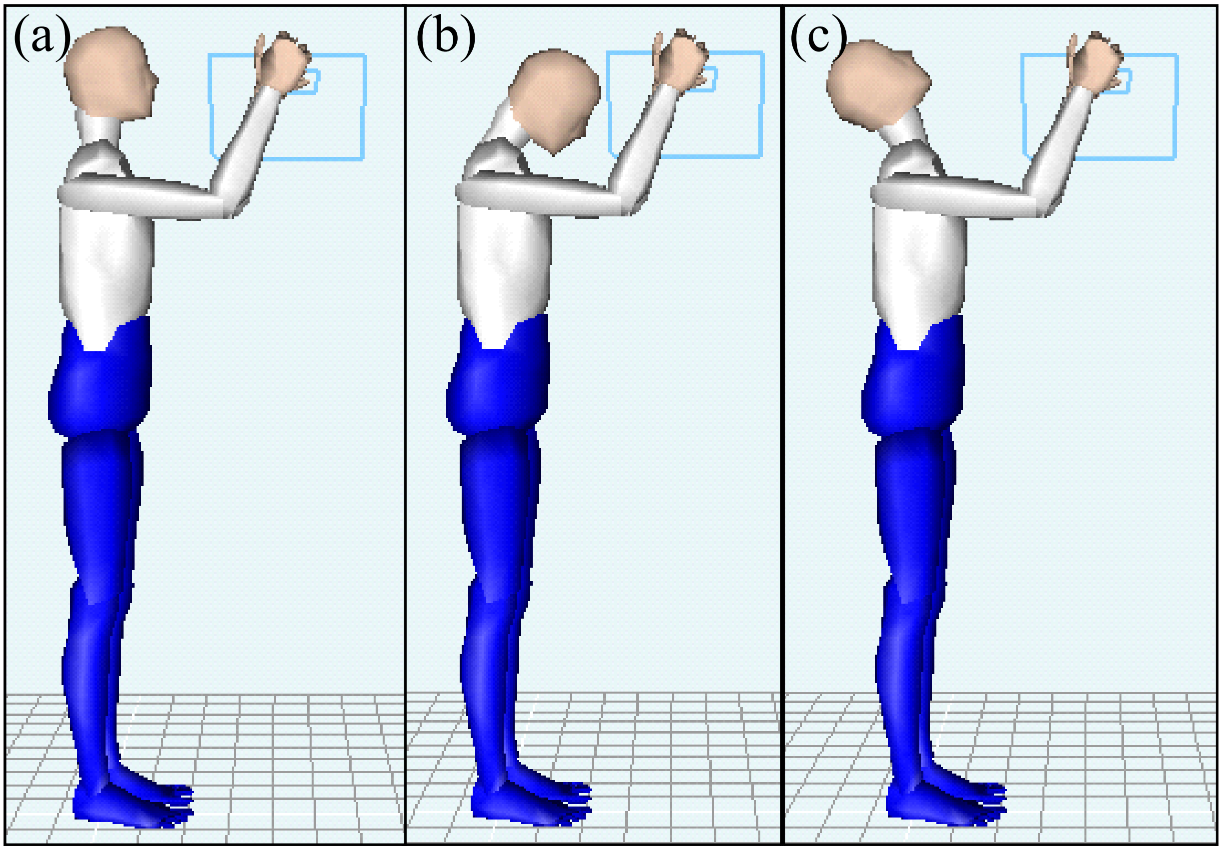


Figure 9: task 3, lifting at the overhead height with neck in (a) neutral, (b) fully flexed, and (c) fully extended postures.

5.4.3 Task 3: Static Lifting at Overhead Height

Workers at various workplaces in many instances are required to perform overhead forceful arm exertions, e.g., manual transfer of large windows and sheet materials. This task was designed to simulate overhead, bimanual, forceful arm exertions. The participants performed overhead lifting tasks with their necks in neutral, fully flexed, and fully extended postures. While lifting at overhead heights, the participants held the shoulder joint at approximately 0° abduction and 90° flexion, the elbow joint at 70-80° of flexion and 0° supination, and the wrist at neutral position (Figure 9).

5.4.4 Task 4: Lifting at Knuckle and Shoulder Heights (Using Isometric Strength Testing Equipment)

At workplaces, workers are frequently involved in lifting weights, approximately from their knuckle height to their shoulder height, e.g., while mixing mortar or grout in the traditional way construction workers lift heavy cement bags (~100 pounds) and load them into the mixer. This experimental task was designed such that the moment arm of the shoulder joint will change and approximately represents the starting and the final positions of a knuckle-to-shoulder lift.

The joint configuration during the static lifting task at the knuckle height involves approximately 0° of abduction and 10°-15° of flexion at the shoulder joint, 25°- 35° of flexion, 0° of supination at the elbow joint and 35°-45° of extension at the wrist (Figure 10 a). The joint configuration during this static lifting task at the shoulder height includes approximately 0° of abduction and 90° of flexion at the shoulder joint, 15° of flexion and 0° of supination at the elbow, and 35°- 45° of extension at the wrist (Figure 10 b). This task was simulated, using isometric strength testing equipment. The data collection details are presented in Section 6.5.

5.4.5 Task 5: Pushing and Pulling at Shoulder Height (Using Isometric Strength Testing Equipment)

In addition to lifting, workers are often involved in the pushing and pulling of (heavy) objects at workplaces, e.g., pushing and pulling of manual carts, sliding of cartons on flat surfaces, and the opening and closing of doors. This task was designed to simulate a bimanual pushing and pulling task at the shoulder height. The participants exerted the forces with the shoulder joint, approximately 0° abduction and 80°-90° flexed, an elbow joint 15°-20° flexed and 0° supinated, and the wrist in neutral position

(Figure 11). While simulating this task in the lab setting, in order to avoid participants from applying body weight, the upper body was stabilized by securing it to a chair, using a harness. The chair was mounted on the wall. This task was also simulated using isometric strength testing equipment; data collection details are presented in Section 6.5. The participants placed their feet at shoulder width apart, resting their feet on their heels with the ankles in an anatomically neutral position.

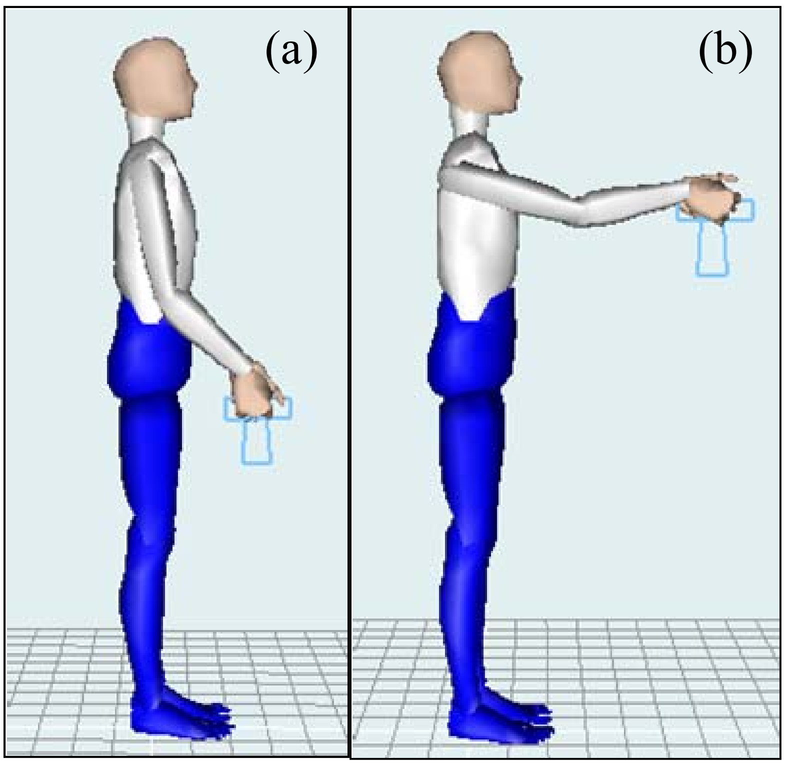


Figure 10: Task 4, lifting at knuckle and shoulder heights.

5.4.6 Task 6: Overhead Pulling (Using Isometric Strength Testing Equipment)

During the overhead pulling task, the participants exerted forces using isometric strength testing equipment. The joint configuration involves approximately 0° abduction and 90° flexion at shoulder joint, 90° of flexion and 0° supination at elbow joint, and the wrist at neutral position (Figure 12).

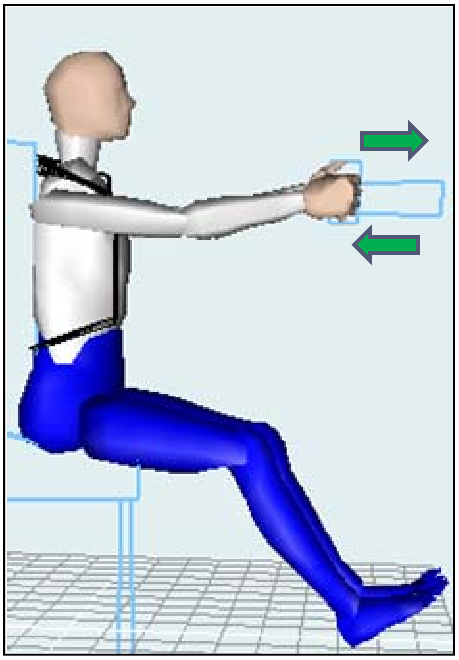


Figure 11: Task 5, pushing and pulling tasks at shoulder height.

5.5 Characteristics of the Tasks

All the tasks tested were isometric, i.e., the participants exerted force in a static posture. During all the tasks except task 5, a participant stood in the normal upright standing posture with her/his feet placed symmetrically and a shoulder-width apart. During each task, participants exerted 25%, 50%, and 75% of the respective maximal strength (lifting or pushing or pulling) during that task at a neutral neck posture, e.g., during task 1, each participant performed a lifting task at elbow height with the neck in neutral, fully flexed, and fully extended posture, exerting 25%, 50%, and 75% of his/her maximum strength at elbow height, and with the neck held in a neutral posture. The duration of each exertion was ten seconds.

During tasks 1 through 3, the participants lifted and held a box with cutout handles on each side. The weight of the box was adjusted by placing metal pieces of different masses in the box. During tasks 4 through 6, the participants exerted the forces using isometric strength testing equipment. The handle height (i.e., horizontal lever arm) of the isometric strength-testing equipment was adjusted to a height, such that the participant could grab the handle maintaining the required joint configuration. Participants then lifted the handle, exerting 25%, 50%, and 75% of the respective maximum static strength. The force exertion during each experimental trial was precisely controlled by providing a visual feedback to the participants. The instantaneous force values were displayed to the participants on a force monitor screen located in front of them. The participants then exerted the target force for ten seconds.

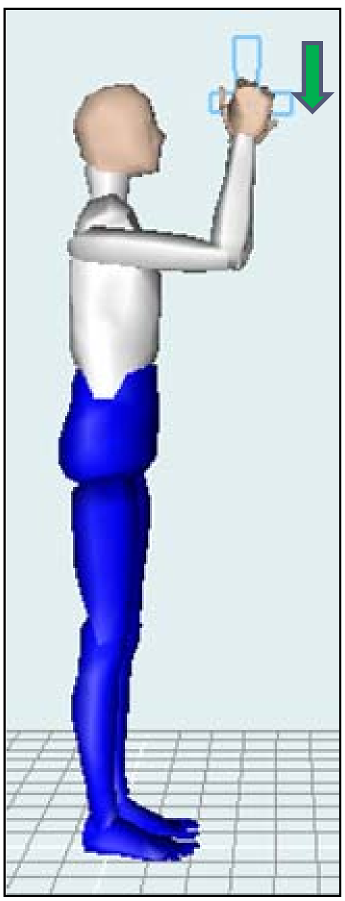


Figure 12: Task 6, Overhead pulling task.

5.6 Experimental Design

Each participant performed 42 experimental trials (Table 1). The trial order was randomized, using the Balanced Latin Square design (Edwards, 1951). The independent variables were the various experimental conditions, e.g., neck postures, weights or level of force exertions, direction of force exertions, and lifting heights. The dependent variables were sternocleidomastoid and upper trapezius muscles activities measured using EMG.

Table 1: Distribution of Experimental Trials

Tasks	Experimental conditions	Number of trials
Task 1: Static lifting at elbow height	Neck postures (neutral, fully flexed, fully extended) = 3 Weights lifted (25%, 50%, and 75%) = 3	**9**
Task 2: Static lifting at shoulder height	Neck postures (neutral, fully flexed, fully extended) = 3 Weights lifted (25%, 50%, and 75%) = 3	**9**
Task 3: Static lifting at overhead height	Neck postures (neutral, fully flexed, fully extended) = 3 Weights lifted (25%, 50%, and 75%) = 3	**9**
Task 4: Lifting at knuckle and shoulder heights	Lifting heights (knuckle and shoulder) = 2 Forces exerted (25%, 50%, and 75%)= 3	**6**
Task 5: Pushing and pulling at shoulder height	Direction of force exertion (pushing, pulling) = 2 Forces exerted (25%, 50%, and 75%) =3	**6**
Task 6: Overhead pulling	Forces exerted (25%, 50%, and 75%) = 3	**3**
Total number of trials		**42**

5.7 Data Collection

The data collection procedures for each participant consisted of four main steps (Figure 13). Prior to the simulation of tasks 1 through 6, each participant was subjected to participant orientation, followed by EMG preparation, determination of maximum strengths, and activation of neck muscles at MVC.

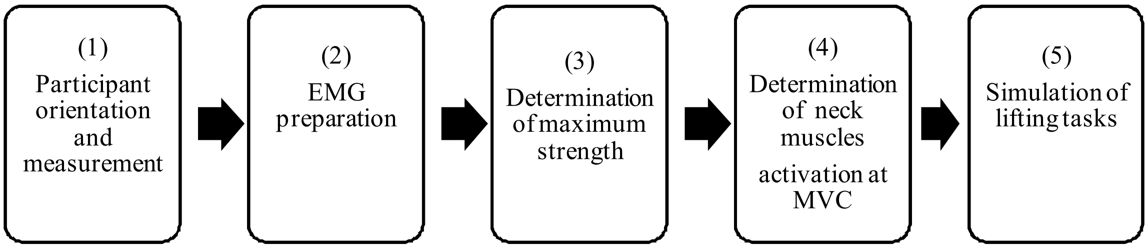


Figure 13: Data collection procedure

5.7.1 Participant Orientation and Measurement

The participants' orientation involved introducing them to the equipment, data collection procedures, and specifics of the experimental tasks. Subsequent to explaining demands of testing, their signatures were obtained on the IRB form. After obtaining their signatures on the IRB form, the demographics (age, height, weight, and sex) as well as some anthropometric measurements, were recorded. The anthropometric measurements included: distance between sternal notch and the mastoid process, distance between the acromion and C7, C6-C7 distance, width of the neck in the anterior-posterior and lateral-medial directions at approximately C4-C5.

5.7.2 EMG Data Collection Preparation

After obtaining the anthropometric measurements, the participants were asked to sit on a chair and the following preparations were carried out to get them ready for the EMG data acquisition:

5.7.2.1 Skin Preparation

The quality of EMG signal relies greatly on the proper skin preparation. Good skin preparation improves the adhesion and the conductance between the electrode and the skin. Common skin preparations involve removing hairs, lightly abrading the skin using a very fine sand paper and cleaning it using alcohol. The removal of hair improves adhesion, especially for sweaty skin types and during testing involving dynamic exertions. Prior to the data collection, the hair in the posterior neck region (if any), was shaved to avoid scenarios of loosening the electrode during the data collection trials. The skin over the sternocleidomastoid and upper trapezius muscle was cleansed with rubbing alcohol. The purpose of cleaning the skin using alcohol is to rid the skin of dead skin cells, dirt, and sweat. A good skin preparation improves conductance between the skin and the electrode.

5.7.2.2 Electrode Placement

Amplitude and various spectral variables of the EMG signal changes drastically with a change in the location of the electrode over the muscle belly. Therefore, it is very important to accurately position the electrode on the muscle belly. A sub-optimal electrode placement could result in erroneous data and misleading results. The electrode location is mostly standardized with respect to the innervation zones of the muscle. The muscle area, where all the end plates of the motor neuron are located, is called the innervation zone (IZ). During a voluntary contraction, a motor neuron discharges an action potential that propagates along its axon; at the motor end plates, the potential is chemically recreated and propagates along muscle fiber membranes toward the tendons

(Cescon et al., 2006). The innervation zone corresponds to a minimum EMG amplitude (Farina et al., 2002).

5.7.2.2.1 Electrode Placement for Sternocleidomastoid Muscle

The sternocleidomastoid muscle originates at the sternum (sterno-) and clavicle (cleido-) heads, passes obliquely across the side of the neck, and inserts at the mastoid process of the temporal bone of the skull (Figure 14). Falla et al. (2002) determined the innervation zone of the sternocleidomastoid muscle by using a linear array of 8 electrodes. The researchers concluded that the innervation zone for the sternocleidomastoid muscle lay around the mid-point of the muscle length and recommended the following location for the bipolar EMG electrodes:

> "Draw a line from the sternal notch to the mastoid process and mark 1/3 the distance from the sternal notch. Draw a second line running perpendicular from the 1/3 mark and extending over sternocleidomastoid muscle. Position bipolar electrodes over the muscle belly at this point, orienting it in the direction of the line joining mastoid process and sternal notch."

In this study the EMG activities from the sternocleidomastoid muscle were obtained using two electrode locations (lower and upper). In addition to the lower location specified by Falla et al. (2002), an additional electrode was also placed in the upper region of the sternocleidomastoid muscle. This electrode was placed at 1/3 the distance from the mastoid process, oriented on the line joining the mastoid process to the sternal notch. The primary reason for using this alternate upper location was to avoid any possible variations in the EMG activities, especially during the static lifting task at the flexed neck posture, as the lower electrode location could be affected by skin movement at the flexed neck posture. The upper electrode location was located at the same distance from the innervation zone as that of the lower placement, and thus was expected to record the optimum EMG signal.

5.7.2.2.2 Electrode Placement for Upper Trapezius Muscle

The upper or cervical trapezius muscle originates in the external occipital protuberance, medial 1/3 of the superior nuchal line, ligamentum nuchae and spinous process of the 7th cervical vertebra and inserts in the lateral 1/3 of the clavicle and acromion process (Figure 15). Farina et al. (2002) determined the innervation zone of the upper trapezius muscle, using a linear array of 16 surface electrodes. The innervation zone was found to be about 52% of the distance between the acromion and C7, measured from the acromion. Authors recommended placing the bipolar electrode at a lateral distance of 25 mm from the mid-point between the acromion and C7.

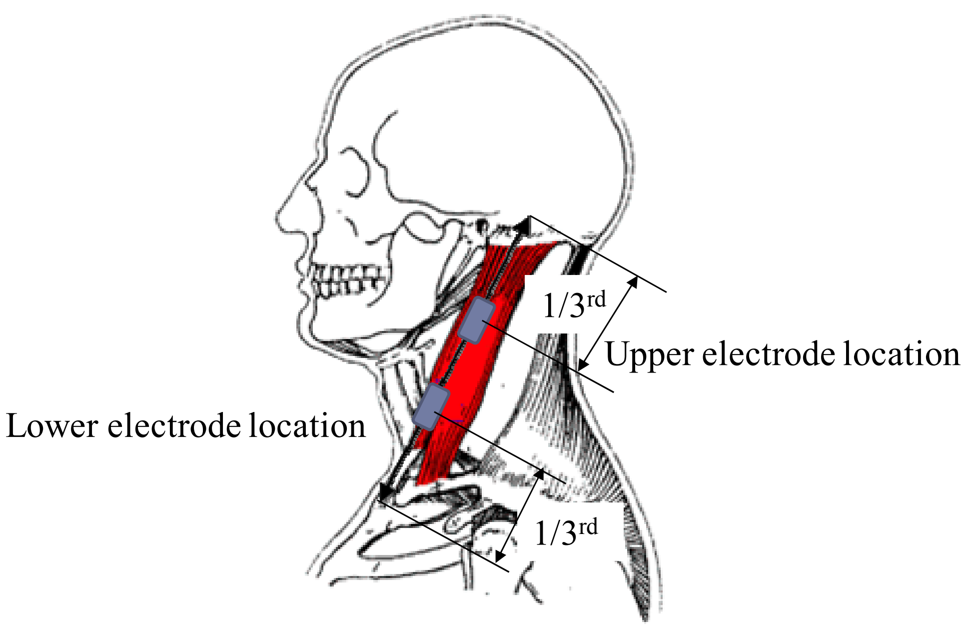


Figure 14: The anatomical orientation of the sternocleidomastoid muscle and the location of the EMG electrodes.

EMG from the upper trapezius muscle was recorded using two electrode locations (lower and upper). The lower electrode was placed at a location along the line joining the acromion and C7, at 1/3 the distance from the acromion, according to published recommendations (Farina et al., 2002). An additional upper electrode was placed between the occiput and C7, at the level of C4 to precisely examine the activities of the upper trapezius muscle in the cervical region (Johnson and Pandyan, 2005). To our knowledge, no standardized electrode location for the upper trapezius muscle along the C4 level has a previous mention in the literature; therefore, an electrode location along the C4 level was finalized, based on measurements from the skeletal models of the cervical spine and pilot EMG data collection. The level of C4 was determined by marking a horizontal line at 2.5 times the distance between the C6-C7 vertebrae above the C7. The electrode at this location was placed slightly inclined (approximately 35º) to the vertical line between the C7 and C4.

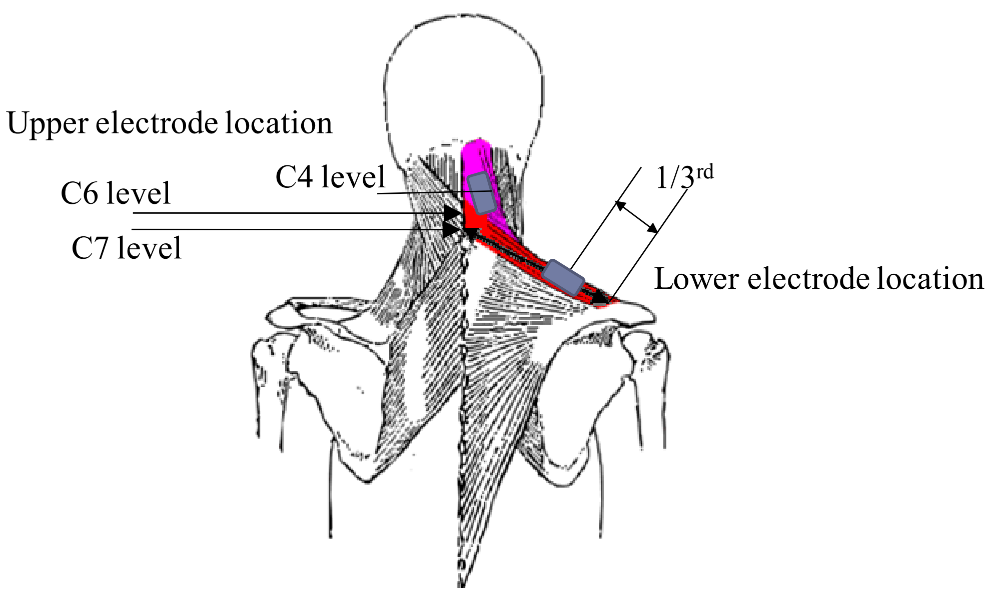


Figure 15: The anatomical orientation of the upper trapezius muscle and the location of the EMG electrodes.

The EMG electrodes were placed bilaterally, thus a total of eight electrode locations (two for each muscle × right and left side × two muscles) were used to collect EMG data from the neck muscles. A disposable reference electrode was applied to the forehead. The electrodes were placed on the neck muscles, using adhesive skin interfaces. The electrodes were then connected to the input modules and the myomonitor. These devices were placed in a black pouch which was hung from the waist of the participant during the simulation of the actual tasks.

5.7.2.2.3 Testing of Electrode Placement

The location of the electrode placement was checked for accuracy and cross talk. The sternocleidomastoid electrode location was checked by a measurable EMG signal during lateral flexion of the head (Pettersen et al., 2005). The upper trapezius electrode location was checked by a measurable EMG signal during flexion-extension of the head and movement of arm elevation with the arms abducted 90º in the scapular plane (Pettersen et al., 2005).

5.7.3 Determination of the Maximum Strengths

The maximum static strengths were determined, using the protocol suggested by Aghazadeh and Ayoub (1985). The height of the handle (i.e., horizontal lever arm) was adjusted to the desired height (knuckle height, elbow height, should height, overhead height), such that the participant could grab the handle maintaining the joint configurations, identical to lifting or pushing-pulling tasks. The participants were instructed to apply force slowly and steadily without a jerking motion, until maximum exertion was reached. Three trials were collected. In case of variability of >10% between trials, a fourth trial was performed and the average of the best three values was determined. Maximum strengths in the following seven postures were determined to simulate the lifting tasks at 25%, 50%, and 75% levels (during all the exertions the neck was held in the neutral posture):

1) lifting at elbow height (task 1)
2) lifting at shoulder height (task 2 and task 4)
3) lifting at overhead height (task 3)
4) lifting at knuckle height (task 4)
5) pushing at shoulder height (task 5)
6) pulling at shoulder height (task 5)
7) overhead pulling (task 6)

A rest period of approximately one minute was given between experimental trials of the same type. While switching between the tasks a rest period of approximately two minutes was given.

5.7.4 Determination of Neck Muscles' Activation at MVC

Comparison of EMG between and within participants involves normalizing the EMG data. Typically, EMG can be normalized with respect to (1) muscle activation at the maximum voluntary contraction or percentage of maximum voluntary contraction (Finsen, 1999; Sommerich et al., 2001); (2) reference muscle activation while performing a standardized task (Mathiassen and Winkel, 1990; Turville et al., 1998) and; (3) the peak or mean activation during the tasks (Yang and Winter, 1984; Winter and Yack, 1987;

Vander Linden and Wilhelm, 1991). The normalization with respect to maximum voluntary contraction has been extensively used in the literature.

The primary action of the upper trapezius muscle, which is elevation of the arms, was considered in a number of occupational studies evaluating the activities of the upper trapezius muscle. The EMG data was normalized with respect to the maximal contraction determined during static exertions holding both of the arms held straight and horizontal in a 90° abduction (Mathiassen et al., 1995). The EMG data for the upper trapezius muscle in this study was normalized with respect to the peak contraction determined during the maximal exertion at the shoulder height (the joint configuration is same as the task 4 (b)).

The sternocleidomastoid muscle was rarely examined in the studies evaluating occupational tasks. The primary action of the sternocleidomastoid muscle is the lateral bending of the neck. The EMG data for the sternocleidomastoid muscle was normalized with respect to the peak activation determined during maximal neck bending tasks (Figure 16).

5.7.5 Simulation of the Experimental Tasks

During this step, participants performed the tasks 1 through 6.

5.8 EMG Data Acquisition

The EMG data was recorded using EMG works 3.5 (Delsys Inc., Boston, USA) software. EMG data was collected continuously during the experimental trials at the rate of 1000 Hz.

5.9 EMG Data Processing

The raw EMG data was exported to the spread sheets using EMG analysis 3.5 software (Delsys Inc., Boston, USA). Custom written visual basic macros (Appendix D) were used in conjunction with the Microsoft excel to perform further analysis on the data. The EMG data was analyzed for the last five seconds, so the data from all the channels was trimmed to obtain data between 5 to 10 seconds. The raw EMG signal from each electrode location was demeaned and then full-wave rectified. The full-wave rectification takes the absolute value of the signal, thereby retaining all of the signal's energy. The full wave rectified EMG signal was then low pass filtered at 4 Hz, using a fourth-order dual pass Butterworth digital filter, to form a linear envelope (Burnett et al., 2007). The low pass filtering suppresses high frequency fluctuations, providing a cleaner amplitude level for better evaluation. The resulting data was averaged to determine the mean absolute values (MAV) (Acierno et al., 1995).

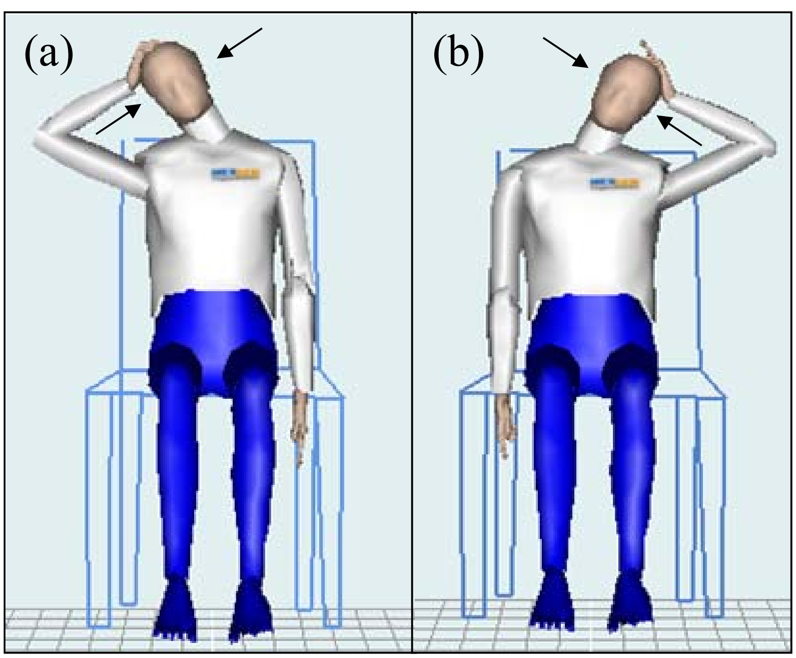


Figure 16: Isometric neck bending tasks used to determine the peak activation for the sternocleidomastoid muscle ((a) right side, (b) left side).

The average MAV was determined for each electrode location during all the experimental trials. The MAV data was normalized with respect to the peak activation for the individual muscle during its MVC (section 6.7.4). The EMG MAV from all the electrodes was normalized to determine the Normalized MAV (N-MAV):

$$N-MAV_{m,n,o,p} = \frac{MAV(m,n,o,p)}{Max[EMG(i,o,p)]}$$

Where,

m=neck posture; fully extended, neutral, fully flexed

n = weight condition; 25%, 50%, 75% of maximum static strength

o = electrode location; right, left on sternocleidomastoid and right, left, upper, lower on upper trapezius muscles

i =MVC exertion; isometric neck bending on right side for sternocleidomastoid muscle on right side, for upper trapezius muscle maximal lifting at the shoulder height

p = participant; 1 to 30

Considering the bimanual and symmetrical nature of the lifting tasks, the neck muscle EMG collected from the right and the left side was averaged for statistical analysis. For the tasks involving different neck postures, the data collected from the lower electrode location for the sternocleidomastoid muscle was inconsistent, due to the substantial amount of skin movement at flexed neck. Therefore, for the tasks involving change in the neck postures for the sternocleidomastoid muscle, only EMG data from the upper electrode location was considered for the analysis.

5.10 Statistical Analysis

Statistical analysis was conducted to evaluate the activities of the neck muscles to

1) compare the experimental conditions within the individual tasks

2) compare the experimental conditions across the tasks

3) compare genders

4) compare muscles

5.10.1 Individual Tasks

Table 2: Within subject variables used for statistical analysis of the individual tasks

Tasks	Within subject variables	
Task 1: Static lifting at elbow height	Neck postures (3 levels)	Weights (3 levels)
	1) neutral 2) flexed 3) extended	1) 25% 2) 50% 3) 75%
Task 2: Static lifting at shoulder height	Neck postures (3 levels)	Weights (3 levels)
	1) neutral 2) flexed 3) extended	1) 25% 2) 50% 3) 75%
Task 3: Static lifting at overhead height	Neck postures (3 levels)	Weights (3 levels)
	1) neutral 2) flexed 3) extended	1) 25% 2) 50% 3) 75%
Task 4: Lifting at knuckle and shoulder heights	Lifting heights (2 levels)	Force exerted (3 levels)
	1) knuckle 2) shoulder	1) 25 % 2) 50% 3) 75%
Task 5: Pushing and pulling at shoulder height	Direction of force application (2 levels)	Force exerted (3 levels)
	1) pushing 2) pulling	1) 25% 2) 50% 3) 75%
Task 6: Overhead pulling	Force exerted (3 levels)	
	1) 25% 2) 50% 3) 75%	

Table 3: Within subject variables used for the statistical analysis for comparing different experimental conditions across the tasks

Effect of weights or level of force exertion	
Forceful exertion (13 levels) 1) lifting at knuckle height in *neutral* neck posture 2) lifting at elbow height in *extended* neck posture 3) lifting at elbow height in *neutral* neck posture 4) lifting at elbow height in *flexed* posture 5) lifting at shoulder height in *extended* neck posture 6) lifting at shoulder height in *neutral* neck posture 7) lifting at shoulder height in *flexed* posture 8) lifting at overhead height in *extended* neck posture 9) lifting at overhead height in *neutral* neck posture 10) lifting at overhead height in *flexed* posture 11) pulling at shoulder height in *neutral* neck posture 12) pushing at shoulder height in *neutral* neck posture 13) pulling at overhead height in *neutral* neck posture	Levels of force exertion (3 levels) 1) 25% 2) 50% 3) 75%
Effect of neck posture	
Forceful exertion (9 levels) 1) lifting 25% weight at elbow height 2) lifting 50% weight at elbow height 3) lifting 75% weight at elbow height 4) lifting 25% weight at shoulder height 5) lifting 50% weight at shoulder height 6) lifting 75% weight at shoulder height 7) lifting 25% weight at overhead height 8) lifting 50% weight at overhead height 9) lifting 75% weight at overhead height	Neck postures (3 levels) 1) extended 2) neutral 3) flexed
Effect of lifting height	
Forceful exertion at knuckle, elbow, shoulder, and overhead (10 levels) 1) lifting at knuckle height in *neutral* neck posture 2) lifting at elbow height in *extended* neck posture 3) lifting at elbow height in *neutral* neck posture 4) lifting at elbow height in *flexed* posture 5) lifting at shoulder height in *extended* neck posture 6) lifting at shoulder height in *neutral* neck posture 7) lifting at shoulder height in *flexed* posture 8) lifting at overhead height in *extended* neck posture 9) lifting at overhead height in *neutral* neck posture 10) lifting at overhead height in *flexed* posture	Lifting weight (3 levels) 1) 25% 2) 50% 3) 75%
Effect of direction of force application	
Forceful exertion in different directions (lifting, pulling, and pushing) (tasks: 5 levels) 1) lifting at shoulder height 2) lifting at overhead height 3) pulling at shoulder height 4) pushing at shoulder height 5) pulling at overhead height	Lifting weight (3 levels) 1) 25% 2) 50% 3) 75%

Statistical analysis was performed using a repeated measures analysis of the variance (ANOVA) model. N-MAV of sternocleidomastoid and upper trapezius muscles (both upper and lower locations) were treated as the dependent variables. A post hoc trend analysis was performed, using Tukey's HSD (Honestly Significant Differences) test when necessary. The significance level was set at 5%. The list of within subject variables for the individual tasks statistical analysis is listed in Table 2.

5.10.2 Across the Tasks

The effect of different experimental conditions across the tasks was evaluated by running a separate repeated measures analysis of variance analysis to understand:

1) effect of weights or level of force exertion

2) effect of neck posture

3) effect of lifting height

4) effect of direction of force application

N-MAV of sternocleidomastoid and upper trapezius muscles (both upper and lower locations) were treated as the dependent variables. A post hoc trend analysis was performed using Tukey's HSD (Honestly Significant Differences) test when necessary. The significance level was set at 5%. The list of within subject variables used for each of the above analysis is listed in Table 3.

5.10.3 Gender Difference

Gender difference was evaluated by using a repeated measures analysis of the variance (ANOVA) model. The within subject variables were the type of exertion (13 levels, same as the effect of weight analysis) and lifting weight (3 levels of 25%, 50%, and 75%) and the between subject variable was the gender (2 levels, male and female).

5.10.4 Muscle Comparison

A paired t-test was used to evaluate the difference in the activities of neck muscles. The activities of the anterior neck muscle (sternocleidomastoid) were compared with the posterior neck muscle (upper trapezius) across 13 different exertions at 25%, 50%, and 75% weight conditions.

CHAPTER 6: BIOMECHANICAL MODELING

6.1 Introduction

EMG data provides information about how hard a muscle is working. Although for most of the muscles, the force exerted is directly proportional to their EMG activities, the actual forces cannot be directly calculated using EMG data. The internal forces exerted by the muscles on the anatomical joint have been evaluated, using biomechanical modeling techniques. These techniques involve developing a biomechanical model to formulate the equilibrium equations and then using an optimization approach to solve the equation.

A number of studies have used biomechanical modeling techniques to calculate the internal forces exerted by muscles on the anatomical structures or joints. Seireg and Arvikar (1973) used a model of lower extremities to evaluate the muscle forces necessary to maintain the human body equilibrium while standing, leaning, and stooping. An et al. (1979) in their model calculated the forces generated by nine muscles at the elbow joint during resisting the elbow flexion moment. Schultz et al. (1983) used a biomechanical model of the lower back to quantify the forces generated by 22 lumber trunk muscles at L3 spine level during standing tasks. Bean et al. (1987) further modified the model presented by Schultz et al. (1983) and used double optimization approach to determine forces generated by 10 low back muscles during isometric lifting tasks. A biomechanical model of neck the consisting of 14 bilateral pairs of muscles was used by Moroney et al.(1988) and Choi and Vanderby (1999) to calculate human neck loads during isometric neck flexion, extension, and left-and-right bending and twisting tasks.

In this study, a biomechanical model of the neck was used, together with a multi-segment model of the upper body to quantify the forces generated at C4-C5 level during isometric lifting task at elbow height. Four bilateral pairs of the muscles, oriented parallel to the cervical spine, were incorporated in the biomechanical model of the neck. The multi-segment model of the upper body consisted of seven body segments.

6.2 Approach

The moment generated at the C4-C5 joint due to the lifting of external loads was determined using a multi-segment model of the upper body. A biomechanical model of the neck was used to determine the moment generated at the C4-C5 joints by the neck muscles. The body segments above and below a transverse cutting plane at the C4-C5 level of the spine remains in the equilibrium during the isometric lifting tasks; hence, the moments generated by the external loads equals the moment generated by the internal muscle. Based on this requirement, a double optimization procedure was used to determine the forces generated by the neck muscles. This procedure involves formulating and solving two linear programming problems simultaneously. In the first problem, the muscle contraction intensity was minimized and during the second problem, the summation of the muscle forces was minimized using the muscle contraction intensity determined during the first problem.

6.3 Multi-Segment Model of the Upper Body

The moment generated at the C4-C5 joint, due to the isometric lifting task at elbow height, was determined using a multi-segment model of the upper body. In the literature, Larivière and Gagnon (1998) and Gagnon et al. (2001) used a multi-segment upper-body model in conjunction with the lower body model, to determine moments at the L5/S1 joints. Based on the upper-body model used by these authors, a seven segment model was constructed to determine the moments at the C4-C5 joint. The upper-body model used in this research is shown in Figure 17. The following segments were included in the model:

1) right and left forearm segments

2) right and left upper arm segments

3) right and left shoulder-C4-C5 segments

4) head segment

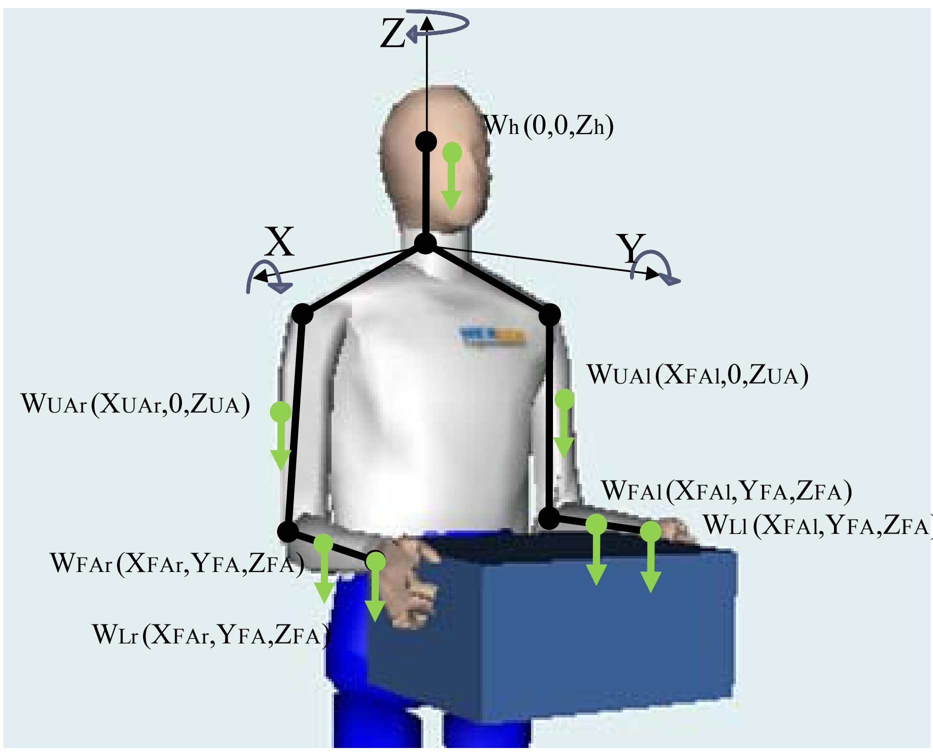


Figure 17: Seven segments upper body model used to determine the moments generated at the C4-C5 joint due to the external loads applied to the hands.

The moment generated at the C4-C5 joint, due to the external loads, was determined using inverse dynamics calculations. The segment length, weight, and center of mass locations data is presented in Table 4. The segment lengths were calculated using formulations provided by Roebuck et al. (1975). The segment center of mass locations were determined, based on the formulations provided by Dempster (1955), and segment weights were determined, using the data provided by Webb Associates (1978).

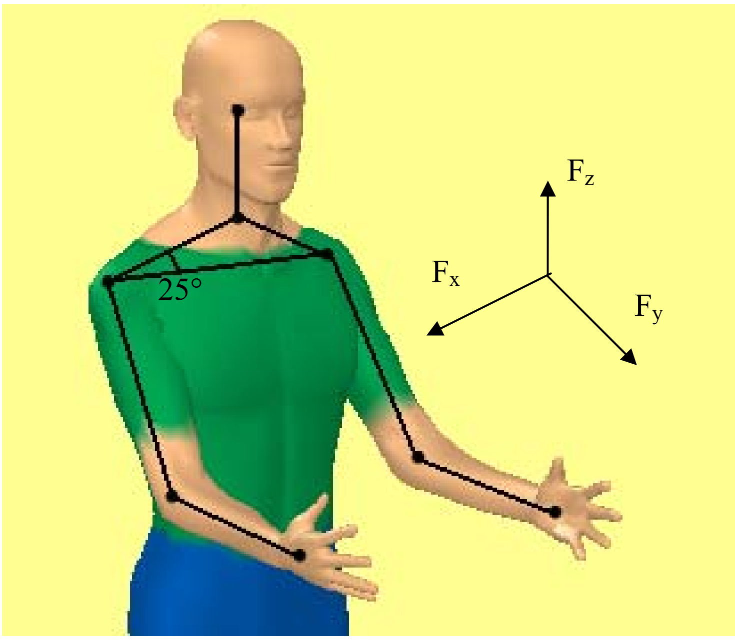


Figure 18: the inclination of the shoulder-C4-C5 segment.

Table 4: The segment length, center of mass locations, and weight data used to calculate the moment generated at the C4-C5 joint using upper body model.

Segment	Length	Center of mass location	Weight
Forearm	=0.146 × Body height	= 0.43 × forearm length	=(0.0232 × body weight)-0.0062
Upper arm	=0.186 × Body height	= 0.436 × upper arm length (from proximal end) Coplanar with XZ plane	=(0.0276 × body weight)-0.0543
Head	= (Body height -0.82 × Body height) × 0.36	collinear with the C4-C5 joint (along Z axis)	=(0.0306 × body weight)+5.4138

The shoulder- C4-C5 segment was considered weightless, inclined 25° at the shoulder joint in the X-Z plane (Figure 18). The center of the C4-C5 joint, shoulder joint and head segment was considered to lie in the same plane (X-Z) along the Z axis of C4-C5 joint.

The stepwise mathematical computation carried out to calculate the moments generated at the C4-C5 joint, based on the seven segment biomechanical model, are presented in the following sections.

6.3.1 Determination of Moment at the C4-C5

The net reaction forces and moments F_x, F_y, F_z, M_x, M_y, M_z at the C4-C5 joint were calculated based on the following equilibrium requirement in X, Y, and Z direction:

$$\sum F_x = 0 \quad \sum F_y = 0 \quad \sum F_z = 0$$
$$\sum M_x = 0 \quad \sum M_y = 0 \quad \sum M_z = 0$$

6.3.1.1 Forces and Moment at the Elbow Joint

Applying the equilibrium condition, elbow joint reaction force and moment can be determined as follows (calculations are shown for right side only):

$$\sum F_z = 0$$
$$\vec{R}_{z_{ELBOW}} + W_{Lr} + W_{FAr} = 0$$
$$\vec{R}_{z_{ELBOW}} = W_{Lr} + W_{FAr}$$

$$\sum M_x = 0$$
$$(W_{Lr} \times Y_{FA}) + (W_{FAr} \times Y_{Lr}) + M_{x_{ELBOW}} = 0$$
$$M_{x_{ELBOW}} = (W_{Lr} \times Y_{FA}) + (W_{FAr} \times Y_{Lr})$$

6.3.1.2 Forces and Moment at the Shoulder Joint

Shoulder joint reaction force and moment necessary to maintain static equilibrium can be determined as follows (calculations are shown for right side only):

$$\sum F_z = 0$$

$$\vec{R}_{z_{SHOULDER}} + \vec{W}_{UAr} + \vec{R}'_{z_{ELBOW}} = 0$$

$$\vec{R}_{z_{SHOULDER}} = \vec{W}_{UAr} + \vec{R}'_{z_{ELBOW}}$$

$$\sum M_x = 0$$

$$M_{x_{ELBOW}} + (\vec{R}'_{z_{ELBOW}} \times 0) + (\vec{W}_{UAr} \times 0) + M_{x_{SHOULDER}} = 0$$

$$M_{x_{SHOULDER}} = M_{x_{ELBOW}}$$

6.3.1.3 Forces and Moment at the C4-C5 Joint.

The forces and moments required to maintain static equilibrium can be determined as follows:

$$\sum F_z = 0$$

$$\vec{R}'_{z_{RIGHT-SHOULDER}} + \vec{R}'_{z_{LEFT-SHOULDER}} + \vec{R}_{z_{C4-5}} + \vec{W}_H = 0$$

$$\vec{R}_{z_{C4-5}} = \vec{R}'_{z_{RIGHT-SHOULDER}} + \vec{R}'_{z_{LEFT-SHOULDER}} + \vec{W}_H$$

$$\sum M_x = 0$$

$$M_{x_{RIGHT-SHOULDER}} + M_{x_{LEFT-SHOULDER}} + M_{y_{C4-5}} = 0$$

$$M_{x_{C4-5}} = M_{x_{RIGHT-SHOULDER}} + M_{x_{LEFT-SHOULDER}}$$

6.4 Biomechanical Model of Neck

Four bilateral pairs of neck muscles were included in the biomechanical model of the neck. The muscle originating or inserting at the shoulder level, crossing the C4-C5 level and running parallel to the cervical spine, were included in the model. The muscles that were included are (Figure 19):

1) sternocleidomastoid

2) levator scapula

3) semispinalis capitis

4) upper trapezius

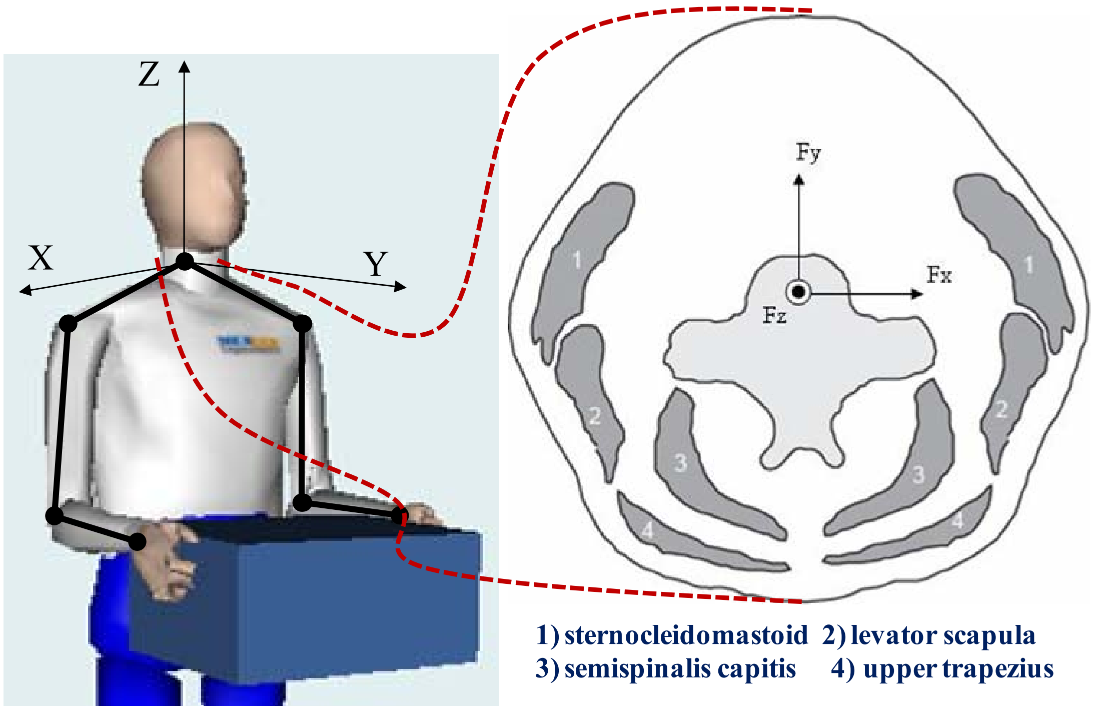


Figure 19: Four muscles included in the biomechanical model of the neck.

The origin of the coordinate system was set at the C4-C5 disc center, with the positive X axis along the right (lateral) direction, and the positive Y axis along the anterior direction, with the positive Z axis acting upward (Figure 20). The point of force application of the individual muscles was assumed to act at the muscle centroid. The muscle cross-sectional area, centroid location, and the direction of the angles of the line of action provided by Moroney et al. (1988) was used to determine the lever arm of an individual muscle (Table 5). A three-dimensional view of the model, showing the line of action of the four muscles included in the model, is shown in Figure 20. The muscle cross sectional areas are expressed in ratio to the product of the neck width (mediolateral) and depth (anterior-posterior). The muscle centroid locations are expressed in ratio to the neck width (Y) and depth (X).

The mathematical equations used to determine the moment generated at the C4-C5 joint by the four neck muscles are as follows:

$$M_x = y_S(S_l + S_r)\cos\lambda_S + y_L(L_l + L_r)\cos\lambda_L + y_L(C_l + C_r) + y_T(T_l + T_r)\cos\lambda_T \quad (1)$$

$$M_x = x_S(S_l - S_r)\cos\lambda_S + x_L(L_l - L_r)\cos\lambda_L + x_L(C_l - C_r) + x_T(T_l - T_r)\cos\lambda_T \quad (2)$$

$$\begin{aligned} M_z = {} & y_S(S_l - S_r)\cos\alpha_S + x_S(S_l - S_r)\cos\beta_S + y_L(L_l - L_r)\cos\alpha_L \\ & + y_T(T_l - T_r)\cos\alpha_T \end{aligned} \quad (3)$$

6.5 Double Optimization Procedure

Based on the requirement that the moment generated at the C4-C5 level by the external load was balanced by the internal forces generated by the neck muscles, two linear programming problems were formulated.

Table 5: Muscle cross sectional area, centroid location, and the muscle line of action parameters used in the biomechanical model.

Muscle	Area* (*A*)	Centroid locations**		Direction of the line of action		
		x	*Y*	X-axis α	Y-axis β	Z-axis λ
Sternocleidomastoid (*S*)	0.0301	0.396	0.088	75	58	37
Levator scapula (*L*)	0.0228	0.323	0.147	110	90	20
Semispinalis capitis (*C*)	0.0248	0.188	0.284	90	90	0
Trapezius (*T*)	0.0144	0.188	0.373	120	90	30

* Areas are expressed in ratio to the product of the neck width (mediolateral) and depth (anterior-posterior)
** centroid locations are expressed in ratio to the neck width and depth

The objective function for the first problem was to minimize the muscle contraction intensity *I*. For the second problem, the objective function was to minimize the cervical spine compressive forces exerted by the neck muscles, using the muscle contraction intensity I^* determined during the first problem. Both the problems were constrained by the equilibrium requirements in the X, Y, and Z directions, respectively.

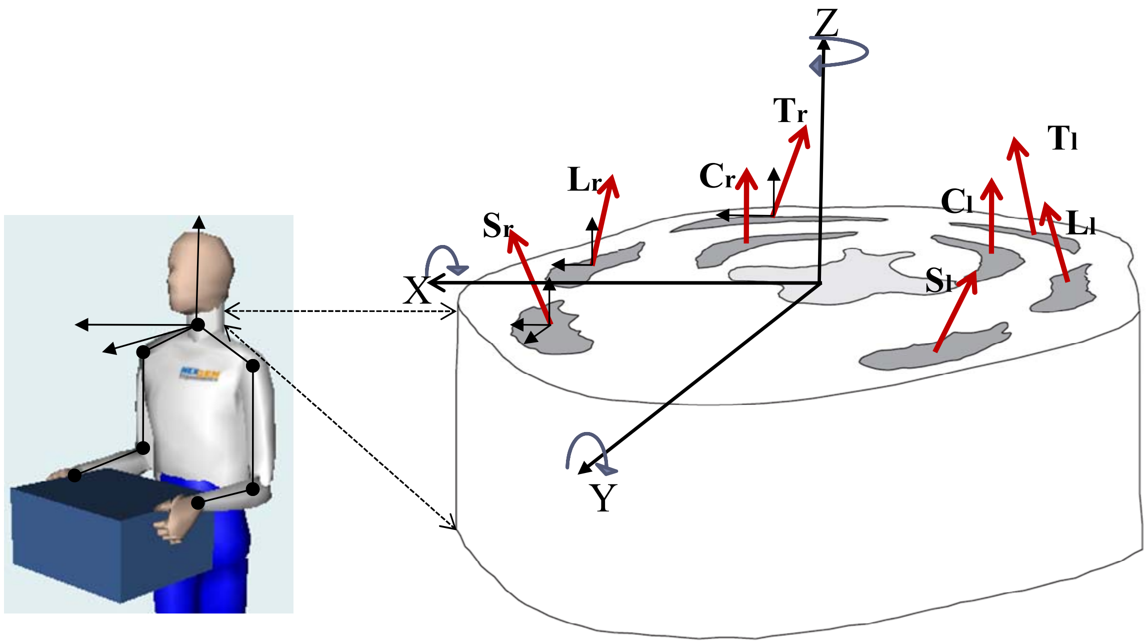


Figure 20: Three dimensional view of the biomechanical model of the neck showing the lines of action of the four muscles; sternocleidomastoid(S), levator scapula (L), semispinalis capitis (C), and upper trapezius (T). Suffix r and l stands for right and left sides.

The formulation of the linear programming problem is as follows:

Let

n be the number of muscle models (8)

r_{ij} be the component of the moment arm for muscle j and axis i

M_i be the component of moment due to the external loads about axis i

A_j be the cross sectional area of muscle j

F_j unknown muscle force

I Muscle force contraction intensity

6.5.1 First Linear Programming Problem

This problem was solved to determine the lowest muscle force intensity value

Minimize I

Subject to constraints:

$$\sum_{j=1}^{n} r_{ij} F_j = M_i \qquad i = 1,2,3$$
$$F_j / A_j \le I \qquad j = 1 \; to \; 8$$
$$F_j \ge 0$$

6.5.2 Second Linear Programming Problem

In the second problem, the sum of muscle contraction forces was minimized using the muscle contraction intensity I^* from the first problem.

$$Minimize \quad \sum_{j=1}^{n} F_j$$

Subject to constraints:

$$\sum_{j=1}^{n} r_{ij} F_j = M_i \qquad i = 1,2,3$$
$$F_j / A_j \le I \qquad j = 1 \; to \; 8$$
$$F_j \ge 0$$

The optimization problem was solved, using the l_p algorithm from the optimization toolbox of MATLAB (The MathWorks, MA, USA) and Microsoft Excel Solver. The forces were calculated for task one (only neutral neck positions).

CHAPTER 7: RESULTS

7.1 Anthropometric and Strength Data

The participants' demographic data (age, weight, and height), anthropometric measurements (neck width and depth), and their maximum isometric strengths at various heights are listed in Table 6. During all the exertions, the maximum isometric strengths of male participants were higher than the female participants, which is in agreement with results reported by Aghazadeh et al. (1997) The data for an individual participant is included in Appendix E.

Table 6: Participants' demographic, anthropometric and strength data

	All	Males	Females
Age	23.2(3.0)	23.6(3.7)	22.8(2.3)
Weight (lb)	163.8(35.5)	185.8(29.8)	141.8(26.3)
Height (cm)	170.3(10.5)	178.6(6.3)	161.0(6.4)
Neck depth (anterior-posterior) (cm)	10.7(1.3)	11.7(0.8)	9.7(0.6)
Neck width (medial-lateral) (cm)	10.8(1.2)	11.8(0.7)	10(0.7)
Elbow height maximum isometric lifting strength (lb)	45.9(14.8)	56.1(13.3)	35.8(7.58)
Shoulder height maximum isometric lifting strength (lb)	26.1(7.65)	30.7(7.25)	21.5(4.84)
Overhead height maximum isometric lifting strength (lb)	50.1(16.8)	60.0(15.9)	40.2(11.1)
Overhead maximum isometric pulling strength (lb)	59.4(21.5)	71.1(20.9)	47.7(15.0)
Shoulder height maximum isometric pushing strength (lb)	62.6(24.2)	70.2(22.8)	55.0(23.8)
Shoulder height maximum isometric pulling strength (lb)	59.8(20.7)	69(21.6)	50.6(15.6)

7.2 Organization

The results of the EMG study are presented in four sections (Figure 21). In Section 1, the trends observed in the activities of the neck muscles during the individual tasks (e.g., task 1: lifting at elbow height, task 2: lifting at shoulder height, etc.) are presented in various subsections. During tasks 1 through 6, the participants performed various types of exertions (lifting, pushing, and pulling), at different heights (knuckle, elbow, shoulder, and overhead), in different neck postures (extension, neutral, and flexion), exerting 25%, 50%, and 75% of their respective maximum strengths. In section 2, behavior of the neck muscles during various experimental conditions across the different tasks (e.g., effect of lifting heights, effect of direction of force application, etc.) are presented. The results of gender difference and comparisons between neck muscles are presented in the third and fourth sections, respectively. The results of biomechanical modeling are presented in Section 5.

7.3 Section 1

7.3.1 Lifting at Elbow Height

The activities of the neck muscles were significantly affected by the weight lifted as well as and the neck posture. A significant interaction (weight × posture) was observed for the sternocleidomastoid muscle activities ($F=10.66$, $P<0.001$). At extended neck posture, an increase in the sternocleidomastoid muscle activities corresponding to the increase in the weight from 25% to 50% to 75% was statistically significant (post hoc analysis at $\alpha = 0.05$) (Figure 22, Table 7). At neutral neck posture, muscle activities increased with the increase in weight from 25% to 75% and from 50% to 75%. At the flexed neck posture, an increase in the muscle activities was statistically insignificant. At each weight condition, i.e., 25%, 50%, and 75%, the muscle activation was highest at the extended neck posture (post hoc analysis, at $\alpha = 0.05$); and statistically, no difference was found between the activation levels at the neutral and flexed neck postures.

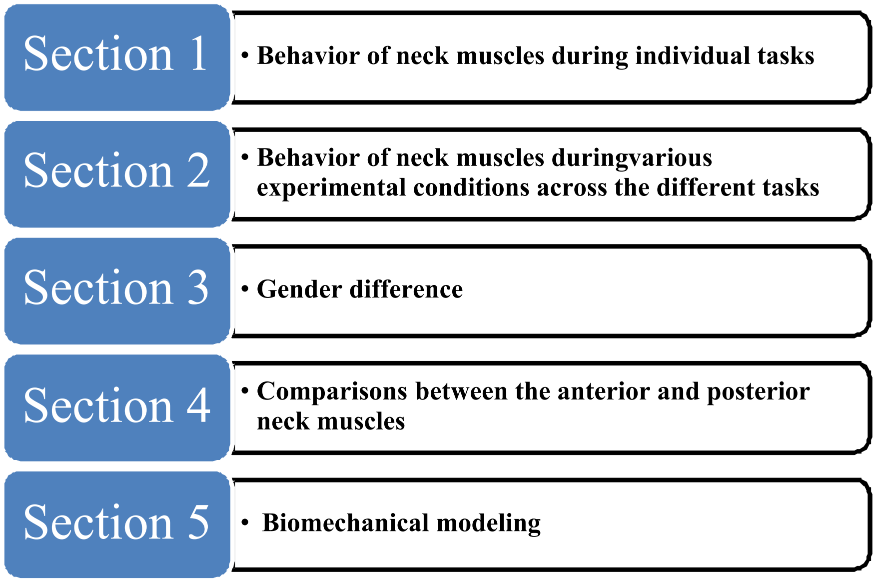


Figure 21: Organization of the results chapter

The activities of the upper trapezius muscle along the C4 level increased significantly with an increase in the weight from 25% to 50% to 75% ($F=88.82$, $P<0.001$) (Figure 23). Based on the post hoc trend analysis at each neck posture, the EMG activation at 50% weight condition was significantly higher than the respective 25% weight condition, and at 75% weight condition, the EMG activation was significantly higher than the respective 25% and 50% weight conditions (at $\alpha = 0.05$) (Table 7). Similar to the upper trapezius muscle along the C4 level, an increase in the weight from 25% to 50% to 75% significantly increased the activities of the upper trapezius muscle along the C7 level ($F=75.13$, $P<0.001$) (Figure 23).

Neck posture significantly affected the activation of the upper trapezius muscle along the C4 level ($F=18.01$, $P<0.001$). At 25%, 50%, and 75% weight conditions, the muscle was found most active at the flexed neck posture, followed by the neutral and extended neck posture. At 25% weight condition, the increase in the activation level with the change in the neck posture from extended to flexed was statistically significant, while a change in the neck posture from neutral to flexed was statistically insignificant (Figure 23 a). At 50% weight condition, an increase in muscle activation with a change in the neck posture from neutral to flexed and from extended to flexed was statistically insignificant. Yet at 75% weight condition, the increase in muscle activation with a change in the neck posture from extended to flexed and from neutral to flexed was statistically significant.

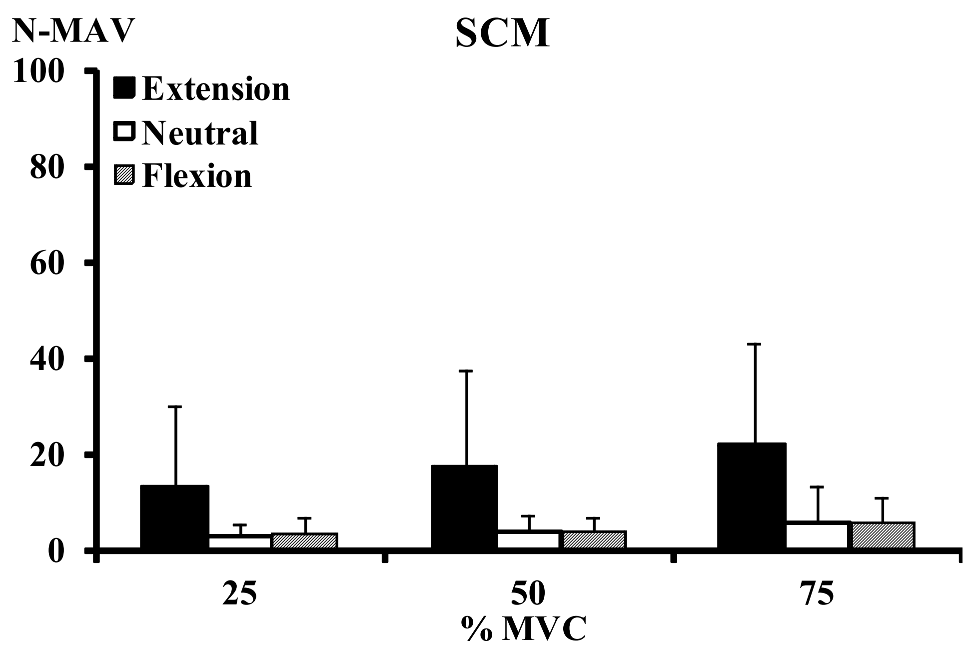


Figure 22: Behavior of the sternocleidomastoid (SCM) muscle (N-MAV values) during lifting 25%, 50%, and 75% weights in neutral, flexed, and extended neck postures at elbow height.

The activation of the upper trapezius muscle along the C7 level was also significantly affected by the neck posture (F=17.98, *P<0.001*) (Figure 23 b). Based on the post hoc analysis, at 25%, 50%, and 75% weight condition, the activation levels at the flexed neck posture were significantly higher than with the corresponding extended and neutral neck postures.

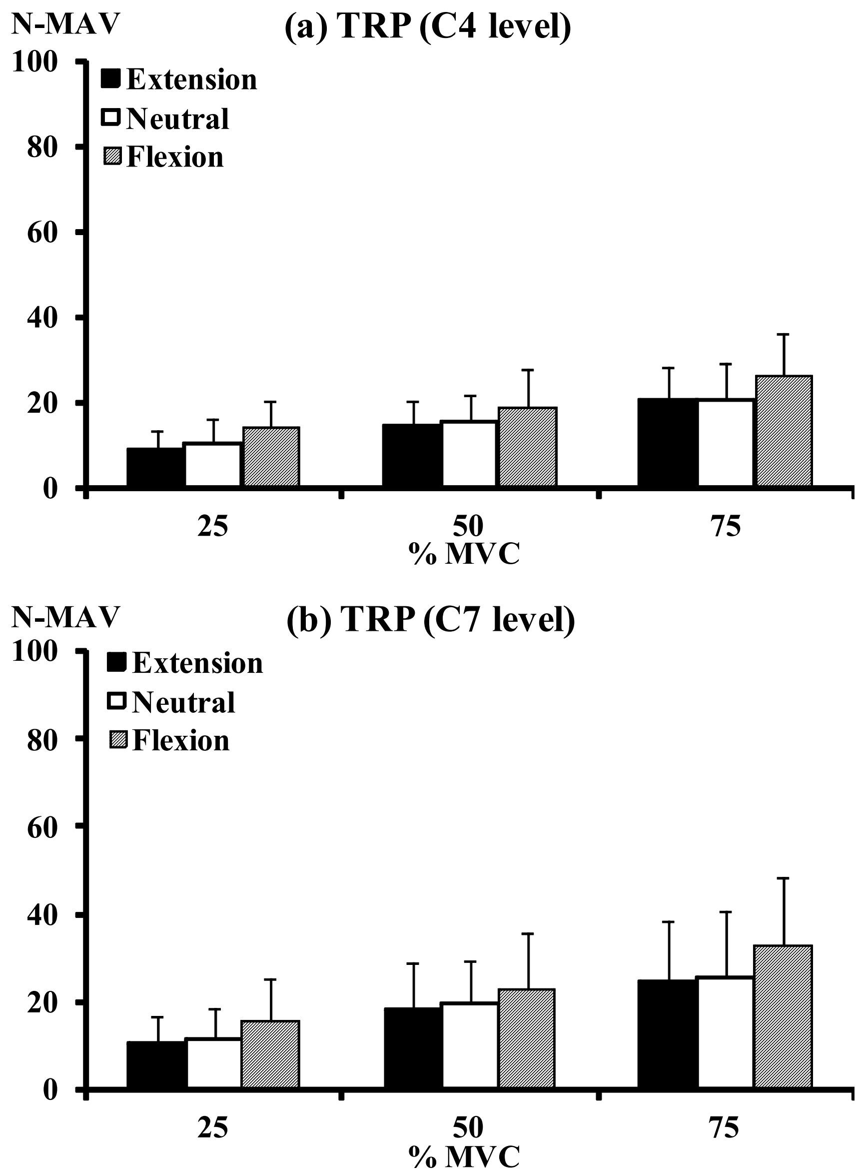


Figure 23: Behavior of the upper trapezius (TRP) muscle along C4 (a) and C7 (b) (N-MAV values) during lifting 25%, 50%, and 75% weights in neutral, flexed, and extended neck postures at elbow height.

In Table 8, different letters are used to indicate the values that are statistically significant. Letters a, b, and c are used for neck postures and x, y, and z are used for weight conditions, e.g., for the sternocleidomastoid muscle at 25% weight condition, the N-MAV during an extended neck posture is higher than with the corresponding neutral and flexed postures, but lower than with the corresponding 50% and 75% weight conditions. A similar method is used to indicate statistically significant values in all the tables.

Table 7: N-EMG values (mean (SD)) for the sternocleidomastoid and upper trapezius muscles during lifting at elbow height. The values marked with the different letters are statistically significant.

	Sternocleidomastoid		
	Neck posture		
Weight	Extension	Neutral	Flexion
25%	$_{(a)}$13.4 (16.7)$^{(x)}$	$_{(b)}$3.14 (2.65)$^{(x)}$	$_{(b)}$3.46 (3.34)$^{(x)}$
50%	$_{(a)}$17.5 (20.2)$^{(y)}$	$_{(b)}$4.18 (3.17)$^{(x)}$	$_{(b)}$4.02 (2.88)$^{(x)}$
75%	$_{(a)}$22.1 (20.9)$^{(z)}$	$_{(b)}$6.15 (7.31)$^{(y)}$	$_{(b)}$5.88 (5.07)$^{(x)}$
	Upper trapezius (along the C4 level)		
25%	$_{(a)}$9.52 (4.14)$^{(x)}$	$_{(ab)}$10.8 (5.58)$^{(x)}$	$_{(a)}$14.4 (6.17)$^{(x)}$
50%	$_{(a)}$14.8 (5.51)$^{(y)}$	$_{(a)}$15.8 (6.04)$^{(y)}$	$_{(a)}$18.8 (9.01)$^{(y)}$
75%	$_{(a)}$20.8 (7.40)$^{(z)}$	$_{(a)}$21.1 (8.02)$^{(z)}$	$_{(a)}$26.4 (9.94)$^{(z)}$
	Upper trapezius (along the C7 level)		
25%	$_{(a)}$10.4 (6.40)$^{(x)}$	$_{(a)}$11.4 (7.21)$^{(x)}$	$_{(b)}$15.7 (9.67)$^{(x)}$
50%	$_{(a)}$18.2 (10.8)$^{(y)}$	$_{(a)}$19.4 (9.90)$^{(y)}$	$_{(b)}$23.0 (12.4)$^{(y)}$
75%	$_{(a)}$24.6 (13.8)$^{(z)}$	$_{(a)}$25.4 (15.2)$^{(z)}$	$_{(b)}$32.7 (15.5)$^{(z)}$

The N-MAV data for the sternocleidomastoid and upper trapezius muscles during lifting at elbow height for all participants is presented in Appendix F. The results of the statistical analysis (ANOVA tables and all-pairwise comparison tests) are presented in Appendix G.

7.3.2 Lifting at Shoulder Height

The overall trend observed in the activities of neck muscles while performing the lifting tasks at the shoulder height was similar to that observed at elbow height.

A significant interaction (weight × posture) was observed for the sternocleidomastoid muscle ($F=2.90$, $P=0.0248$). Based on the post hoc trend analysis ($\alpha = 0.05$), at extended neck posture, increase in the weight from 25% to 75% and from 50% to 75% significantly increased the muscle activities (Figure 24 a, Table 8). At neutral and flexed neck postures, an increase in the muscle activities coupled with the increase in the weight from 25% to 75% was statistically significant. Yet an increase in the muscle activities corresponding to the increase in the weight from 25% to 50% and from 50% to 75% was statistically insignificant. At all the weight conditions, the muscle was most active at the extended neck posture. The increase in the muscle activation with the change in the neck posture from neutral to extended and from flexed to extended was statistically significant (post hoc analysis at $\alpha = 0.05$).

A significant interaction (weight × posture) was observed for the upper trapezius muscle along the C4 level ($F=8.12$, $P<0.001$) while performing the lifting tasks at the shoulder heights. At an extended neck posture, the increase in the muscle activation was significant, corresponding to the increase in weight from 25% to 75%, and from 50% to 75%, but was insignificant for the increase in the weight from 25% to 50% (Figure 24 b, Table 8). At a neutral neck posture, the increase in muscle activities with the increase in the weight from 25% to 50% and 25% to 75% was significant. At flexed neck postures, an increase in the weight from 25% to 50%, 25% to 75%, and 50% to 75% significantly increased the activities of the upper trapezius muscle. At each weight condition, the muscle was most active at an extended neck posture, followed by the neutral and flexed neck postures. Increase in the muscle activation with the change in the neck posture from extension to flexion was statistically significant at 25%, 50%, and 75% weight conditions, but from neutral to flexion was statistically significant at 50% and 75% weight conditions only.

The activation of the trapezius muscle along the C7 level also showed a significant weight × posture interaction (F=4.00, $P=0.0044$). At the neutral and flexed neck postures, an increase in the weight from 25% to 50% to 75% significantly increased the muscle activation (Figure 24 c, Table 8). At the extended neck posture, the muscle activation increased significantly with an increase in weight from 25% to 75% and from 50% to 75%. In general, muscle was found most active at the flexed neck posture. The increase in the muscle activation with the change in neck posture from extension to flexion and from neutral to flexion was statistically significant at 50% and 75% weight conditions. At the 25% weight condition, an increase in the muscle activation with the change in the neck from extension to flexion and from neutral to flexion was statistically insignificant.

The N-MAV data for the sternocleidomastoid and upper trapezius muscles during lifting at shoulder height for all participants is presented in Appendix F. The results of the statistical analysis (ANOVA tables and all-pairwise comparison test) are presented in Appendix G.

7.3.3 Lifting at Overhead Height

The overall trend observed in the activation of the neck postures at the overhead height with respect to the change in the neck postures, as well as an increase in the lifting

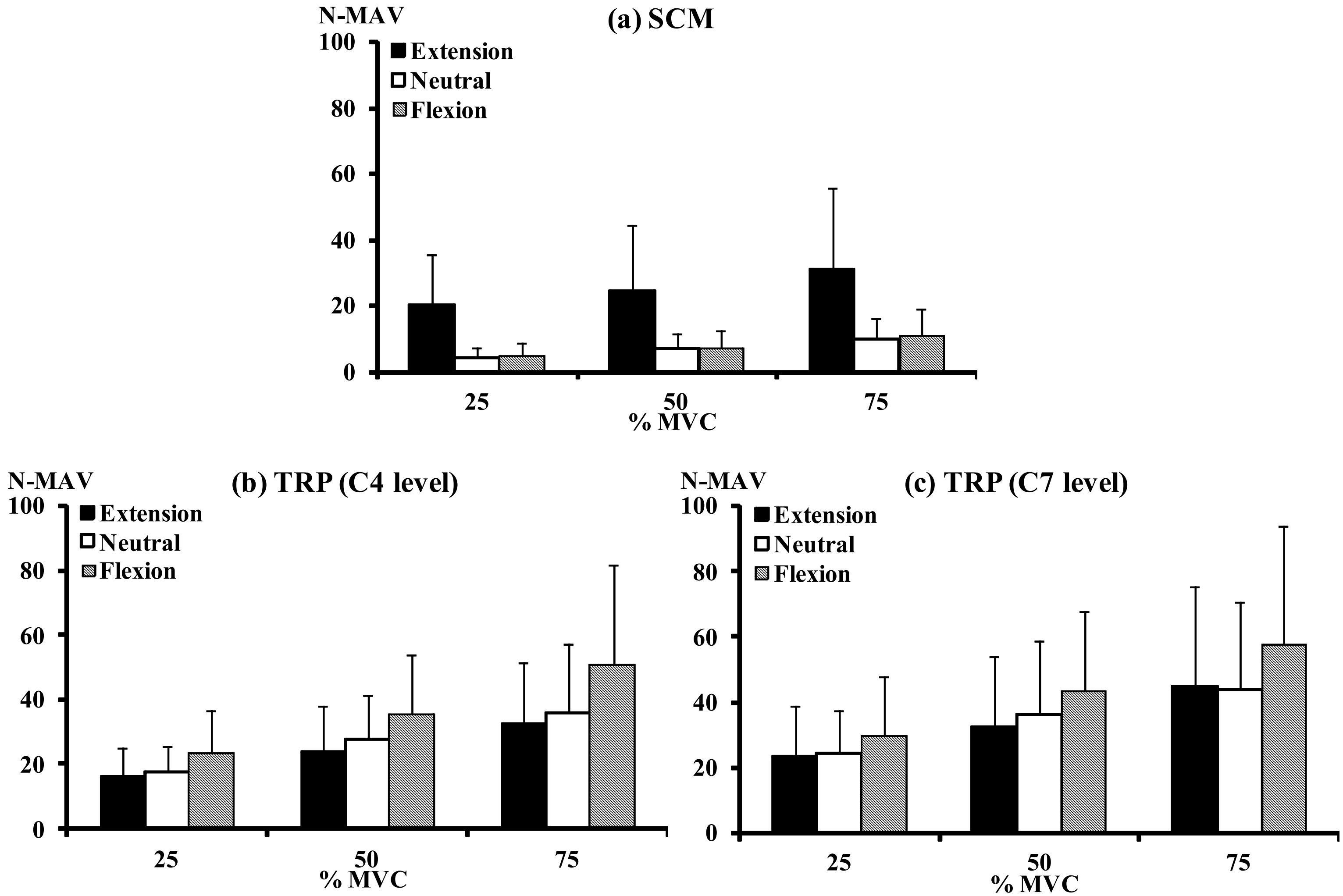


Figure 24: Behavior of the sternocleidomastoid (SCM) muscle (a) and the upper trapezius (TRP) muscle along C4 (b) and C7 (c) (N-MAV values) while the participants lifting 25%, 50%, and 75% weights at shoulder height with their neck in the neutral, flexed, and extended neck postures

Table 8: N-EMG values (mean (SD)) for the sternocleidomastoid and upper trapezius muscles during lifting at shoulder height. The values marked with the different letters are statistically significant.

	Sternocleidomastoid		
	Neck posture		
Weight	Extension	Neutral	Flexion
25%	(a)20.3 (14.9) (x)	(b)4.20 (3.04) (x)	(b)4.64 (4.00) (x)
50%	(a)24.2 (19.9) (x)	(b)6.88 (4.84) (xy)	(b)7.16 (5.19) (xy)
75%	(a)30.8 (24.7) (y)	(b)9.81 (6.37) (y)	(b)11.0 (8.12) (y)
	Upper trapezius (along the C4 level)		
25%	(a)16.4 (8.48) (x)	(ab)17.9 (7.56) (x)	(b)23.7 (12.6) (x)
50%	(a)23.7 (14.3) (x)	(a)27.5 (14.1) (y)	(b)35.5 (18.4) (y)
75%	(a)32.7 (18.8) (y)	(a)35.9 (21.1) (y)	(b)50.7 (30.7) (z)
	Upper trapezius (along the C7 level)		
25%	(a)23.5 (15.2) (x)	(a)24.4 (13.1) (x)	(a)29.4 (18.5) (x)
50%	(a)32.8 (21.4) (x)	(a)36.2 (22.3) (y)	(b)43.2 (24.3) (y)
75%	(a)44.7 (30.5) (y)	(a)44.0 (26.4) (z)	(b)57.6 (36.2) (z)

weight, was similar to that observed at the elbow and shoulder height. The activation of the sternocleidomastoid and the upper trapezius muscles increased with the increase in weight. The anterior muscle, i.e., sternocleidomastoid muscle, was most active at the extended neck posture, while the posterior, i.e., upper trapezius muscle was most active at the flexed neck posture. The activation of the sternocleidomastoid muscle showed a significant interaction (weight × posture) (F=3.72, *P=0.0069*) while performing lifting at the overhead heights. At the extended neck posture, muscle activation increased significantly with the increase in the weight from 25% to 50% to 75% (Figure 24 a, Table 9). At neutral and flexed weight conditions, the increase in the muscle activation was statistically significant with the increase in the weight from 25% to 75% and from 50% to 75%. At each weight condition, the muscle activation at the extended neck posture was significantly higher than the respective neutral and flexed neck postures. No difference was found in the muscle activation with the change in the neck posture from neutral to flexion.

Table 9: N-EMG values (mean (SD)) for the sternocleidomastoid and upper trapezius muscles during lifting at overhead height. The values marked with the different letters are statistically significant.

	Sternocleidomastoid		
	Neck posture		
Weight	Extension	Neutral	Flexion
25%	$_{(a)}$24.9 (20.9) $^{(x)}$	$_{(b)}$5.96 (4.78) $^{(x)}$	$_{(b)}$6.38 (5.97) $^{(x)}$
50%	$_{(a)}$34.2 (26.7) $^{(y)}$	$_{(b)}$10.3 (7.97) $^{(x)}$	$_{(b)}$9.68 (8.39) $^{(x)}$
75%	$_{(a)}$40.4 (28.1) $^{(z)}$	$_{(b)}$16.6 (11.5) $^{(y)}$	$_{(b)}$16.1 (13.1) $^{(y)}$
	Upper trapezius (along the C4 level)		
25%	$_{(a)}$19.0 (11.4) $^{(x)}$	$_{(a)}$17.8 (8.07) $^{(x)}$	$_{(a)}$22.9 (10.8) $^{(x)}$
50%	$_{(a)}$26.9 (12.1) $^{(x)}$	$_{(a)}$29.0 (18.9) $^{(y)}$	$_{(a)}$34.8 (18.8) $^{(y)}$
75%	$_{(a)}$40.1 (27.7) $^{(y)}$	$_{(a)}$42.4 (21.7) $^{(z)}$	$_{(b)}$53.6 (34.5) $^{(z)}$
	Upper trapezius (along the C7 level)		
25%	$_{(a)}$25.6 (15.9) $^{(x)}$	$_{(a)}$25.0 (15.0) $^{(x)}$	$_{(a)}$32.1 (16.7) $^{(x)}$
50%	$_{(a)}$36.1 (19.9) $^{(y)}$	$_{(a)}$36.4 (17.8) $^{(y)}$	$_{(b)}$46.3 (24.3) $^{(y)}$
75%	$_{(a)}$48.8 (21.1) $^{(z)}$	$_{(a)}$50.9 (22.0) $^{(z)}$	$_{(b)}$60.7 (31.4) $^{(z)}$

The activation of the upper trapezius muscle along the C4 level increased with an increase in the weights lifted (F=49.62, *P<0.001*). At neutral and flexed neck postures, the muscle activities increased significantly with the increase in weight from 25% to 50% to 75%. At an extended neck posture, the increase was statistically significant only for the increase in weight from 25% to 75% and from 50% to 75 (Figure 24 b, Table 9). At each weight condition, the muscle was most active at the flexed neck posture, followed by the neutral and extended neck posture. The neck posture significantly affected the activation of the upper trapezius muscle (F=22.78, *P<0.001*). During all the weight conditions, the activation of the muscle at the flexed neck posture was higher than the respective neutral and extended neck postures. Based on the post hoc analysis, the increase in muscle activation with the change in neck posture from extension to flexion and from neutral to flexion was significant only at the 75% weight condition.

Increase in the weights significantly increased the activation of the upper trapezius muscle along the C7 level (F=100.25, *P<0.001*). At all the neck postures, the muscle activities increased significantly with an increase in the weight from 25% to 50% to 75%. The neck posture significantly affected the activation of the muscle (F=21.18, *P<0.001*). At 50% and 75% weight conditions, the muscle activation at the flexed neck posture was significantly higher than the respective extended and neutral neck postures (Figure 24 c, Table 9). At a 25% weight condition, the corresponding increase was statistically insignificant. At all weight conditions, no difference was found in the muscle activation with the change in the neck posture from extension to neutral.

The N-MAV data for the sternocleidomastoid and upper trapezius muscles during lifting at overhead height for all participants is presented in Appendix F. The results of

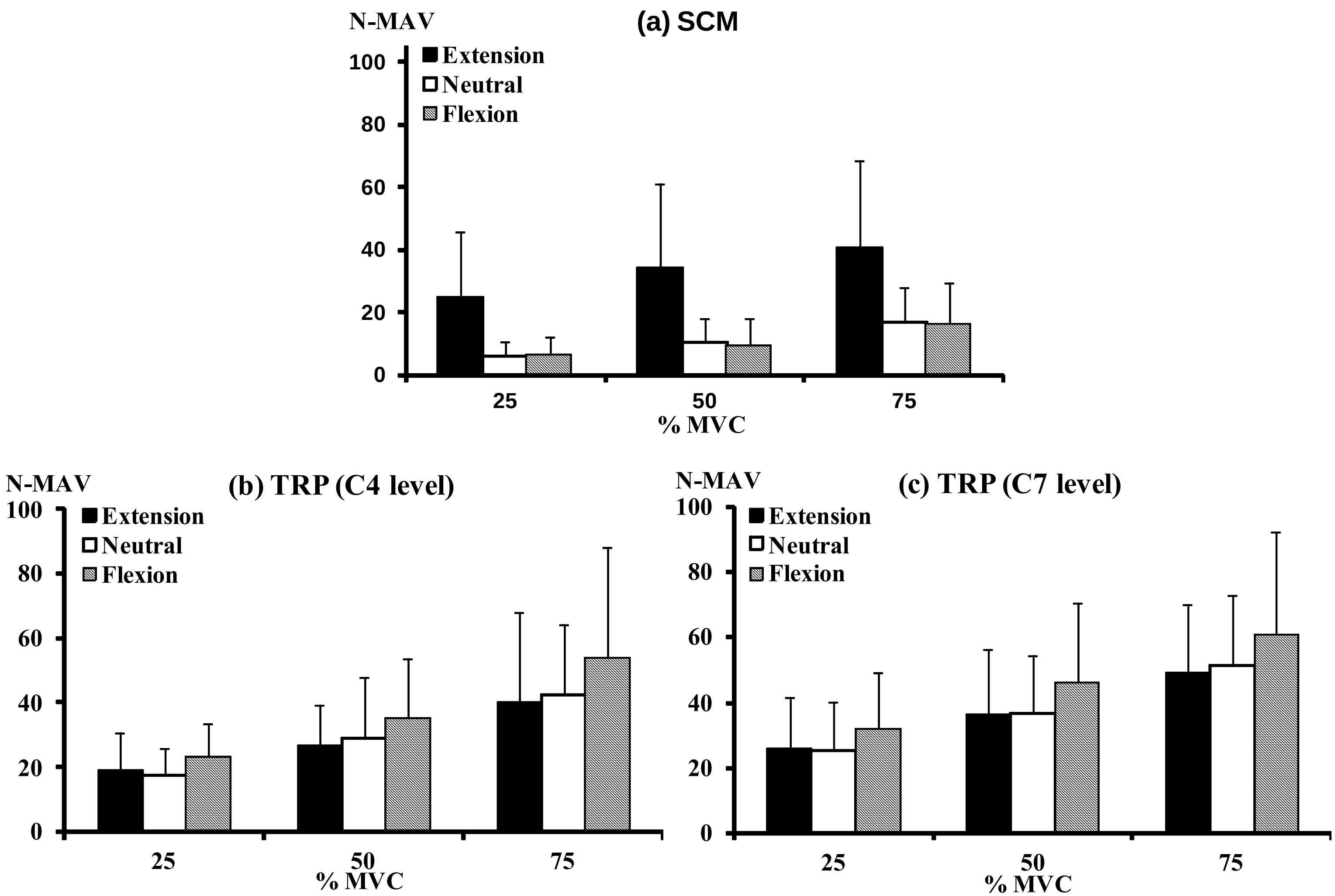


Figure 25: Behavior of the sternocleidomastoid (SCM) muscle (a) and the upper trapezius (TRP) muscle along C4 (b) and C7 (c) (N-MAV values) during lifting at overhead heights. The participants lifted 25%, 50%, and 75% of their maximum strengths with their neck in neutral, flexed, and extended postures.

the statistical analysis (ANOVA tables and all-pairwise comparison test) are presented in Appendix G.

7.3.4 Lifting at Knuckle and Shoulder Heights (Using Isometric Strength Testing Equipment)

Lifting tasks that were performed using the lift platform at the knuckle and shoulder heights significantly affected the activation of the neck muscles. A significant weight × lifting height interaction was observed for sternocleidomastoid muscle activities (F=23.10, $P<0.001$). Based on the post hoc analysis, a shoulder height increase in muscle activities with an increase in the exertion from 25% to 50% to 75% was statistically significant (Figure 24 a, Table 10). The increase in the muscle activities with an increase in lifting weights was statistically insignificant at knuckle height. However, at 50% and 75% weight conditions, muscle activities at shoulder height were significantly higher than at the knuckle height.

A significant weight × lifting height interaction was also observed for the activities of the upper trapezius muscle along the C4 (F=50.85, $P<0.001$) and C7 (F=30.15, $P<0.001$) levels. At both the levels, while lifting at shoulder height, an increase in the muscle activities with the increase in the exertion from 25% to 50% to 75% was statistically significant (Figure 24 b, Figure 24 c, Table 10). At knuckle height, an increase in the exertion from 25% to 75% and from 50% to 75% significantly increased the muscle activities. Increase in the activation, corresponding to the increase in the exertion from 25% to 50%, was statistically insignificant. For both the muscle locations, the muscle activities at shoulder height were significantly higher than at the knuckle height at 25%, 50%, and 75% weight conditions.

Table 10: N-EMG values (mean (SD)) for the sternocleidomastoid and upper trapezius muscles during lifting at knuckle and shoulder heights with neck in the neutral posture.

	Sternocleidomastoid	
	Lifting heights	
Weight	Knuckle	Shoulder
25%	$_{(a)}$3.89 (3.35)$^{(x)}$	$_{(a)}$6.78 (6.14)$^{(x)}$
50%	$_{(a)}$4.16 (3.51)$^{(x)}$	$_{(b)}$10.4 (10.0)$^{(y)}$
75%	$_{(a)}$5.02 (4.32)$^{(x)}$	$_{(b)}$16.1 (14.4)$^{(z)}$
	Upper trapezius (along the C4 level)	
25%	$_{(a)}$9.15 (4.10)$^{(x)}$	$_{(b)}$18.8 (5.77)$^{(x)}$
50%	$_{(a)}$10.1 (4.48)$^{(x)}$	$_{(b)}$25.7 (8.14)$^{(y)}$
75%	$_{(a)}$13.4 (6.98)$^{(y)}$	$_{(b)}$36.4 (11.3)$^{(z)}$
	Upper trapezius (along the C7 level)	
25%	$_{(a)}$7.62 (4.85)$^{(x)}$	$_{(b)}$24.7 (10.7)$^{(x)}$
50%	$_{(a)}$11.1 (6.40)$^{(x)}$	$_{(b)}$32.7 (11.7)$^{(y)}$
75%	$_{(a)}$15.5 (9.10)$^{(y)}$	$_{(b)}$44.8 (17.7)$^{(z)}$

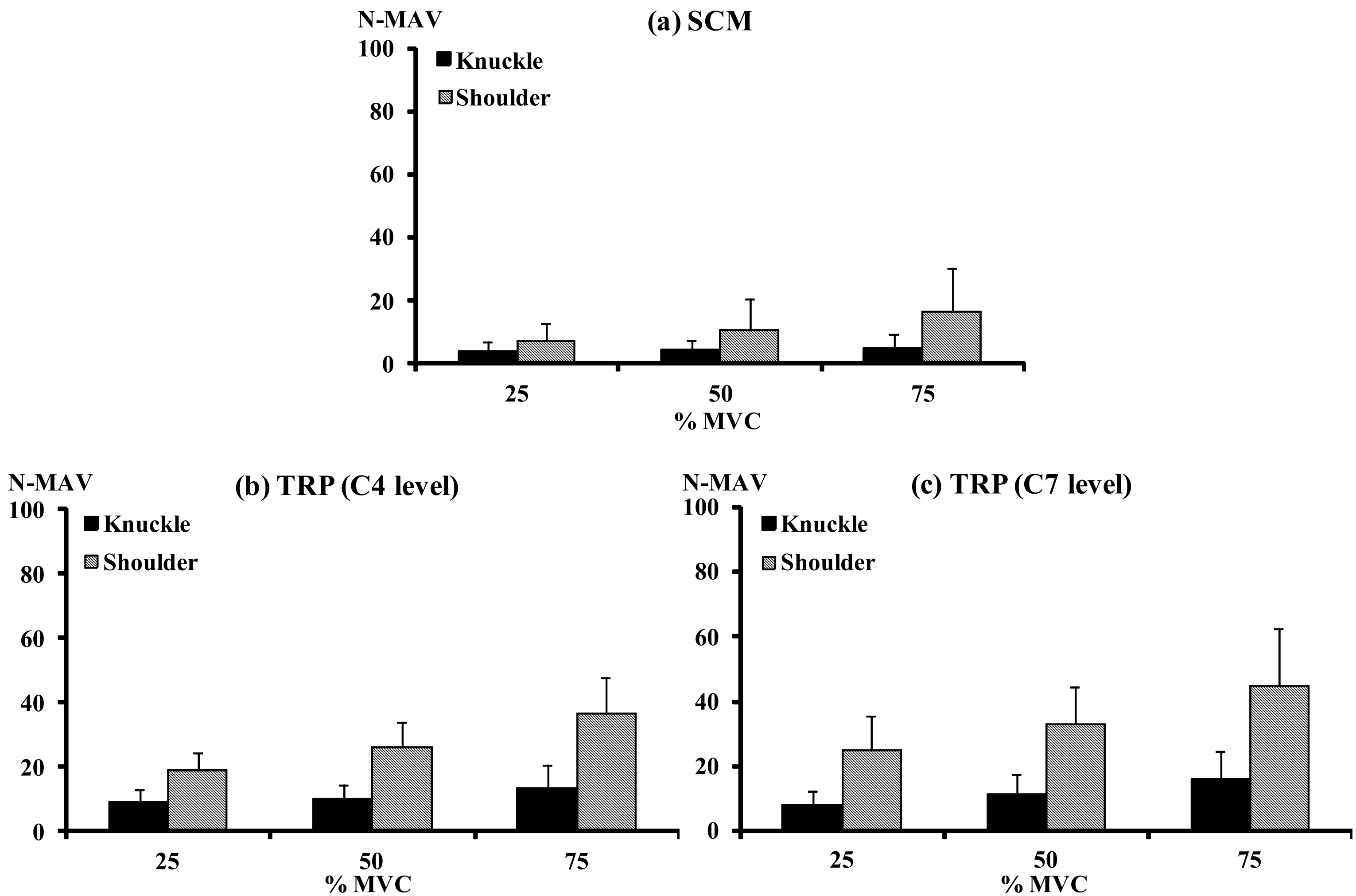


Figure 26: Behavior of the sternocleidomastoid muscle (a) and the upper trapezius (TRP) muscle along C4 (b) and C7 (c) (N-MAV values) while participants exerting 25%, 50%, and 75% of their maximum strengths at knuckle and shoulder heights with neck in neutral posture.

Appendix F presents N-MAV data for the sternocleidomastoid muscle and the upper trapezius muscle along C4 and C7, with participants exerting 25%, 50%, and 75% of their maximum strengths at knuckle and shoulder heights in neutral neck posture. The results of the statistical analysis (ANOVA tables and all-pairwise comparison test) are presented in Appendix G.

7.3.5 Pushing and Pulling at Shoulder Height (Using Isometric Strength Testing Equipment)

The activation of the neck muscles while performing pushing and pulling tasks was affected by an increase in the exertion level. For the sternocleidomastoid muscle, during the pushing and pulling tasks at shoulder height an increase in the level of exertion also increased the muscle activation (F=5.38, *P=0.0072*). During pulling and pushing, an increase in muscle activation was statistically significant with the increase in the exertion level from 25% to 75% (Figure 27a, Table 11). The increase in muscle activation with the increase in the exertion level from 25% to 50% and from 50% to 75% was statistically not significant. In general, in a comparison of pulling versus pushing, the muscle worked slightly harder while pulling, compared to pushing; however, activation levels were not statistically significant (F=3.20, *P=0.0843*).

The activities of the upper trapezius muscle along C4 during pushing and pulling exertions increased, corresponding to the increase in the level of exertion (F=9.53, *P=0.0003*). During pulling, an increase in the exertion level from 25% to 75% and from 50% to 75% significantly increased the muscle activation (Figure 27b, Table 11). While pushing, an increase in the muscle activation with the increase in the level of exertion was statistically insignificant. In comparing pulling with pushing, the change in the direction of force application significantly affected the muscle activation (F=13.15, *P=0.0011*). Higher levels of activation were observed during pulling compared to the pushing, but the N-MAV values were statistically significant only during the 75% exertion level.

The effect of increase in the level of exertion on the activities of the upper trapezius muscle along the C7 level was similar to that observed along the C4 level. The muscle activation increased significantly with an increase in the level of force exertions (F=5.33, *P=0.0075*). Muscle activation was significantly higher during the 75% exertion while pulling and an increase in muscle activation coupled with the increase in the level of exertion during pushing, was statistically insignificant (Figure 27c, Table 11). Therefore, the direction of force application significantly affected the muscle activation (F=27.45, *P<0.001*). During all the exertion levels, the activities of the muscle were significantly higher during the pulling, compared to that while pushing.

The N-MAV data for the sternocleidomastoid muscle and the upper trapezius muscle along levels C4 and C7 while participants performed pushing and pulling exertions is presented in Appendix F. The results of the statistical analysis (ANOVA tables and all-pairwise comparison test) are presented in Appendix G.

7.3.6 Overhead Pulling (Using Isometric Strength Testing Equipment)

While performing overhead pulling, the activities of the sternocleidomastoid muscle increased significantly with the increase in the exertion level (F=4.64, *P<0.0136*). The activities during the 75% exertion were significantly higher than the respective 25% and 50% exertion levels (Figure 27, Table 12).The activities of the upper trapezius muscle along C4 (F=3.03, *P=0.0561*) and C7 (F=2.29, *P<0.1100*) were not affected by the increase in exertion level during overhead pulling.

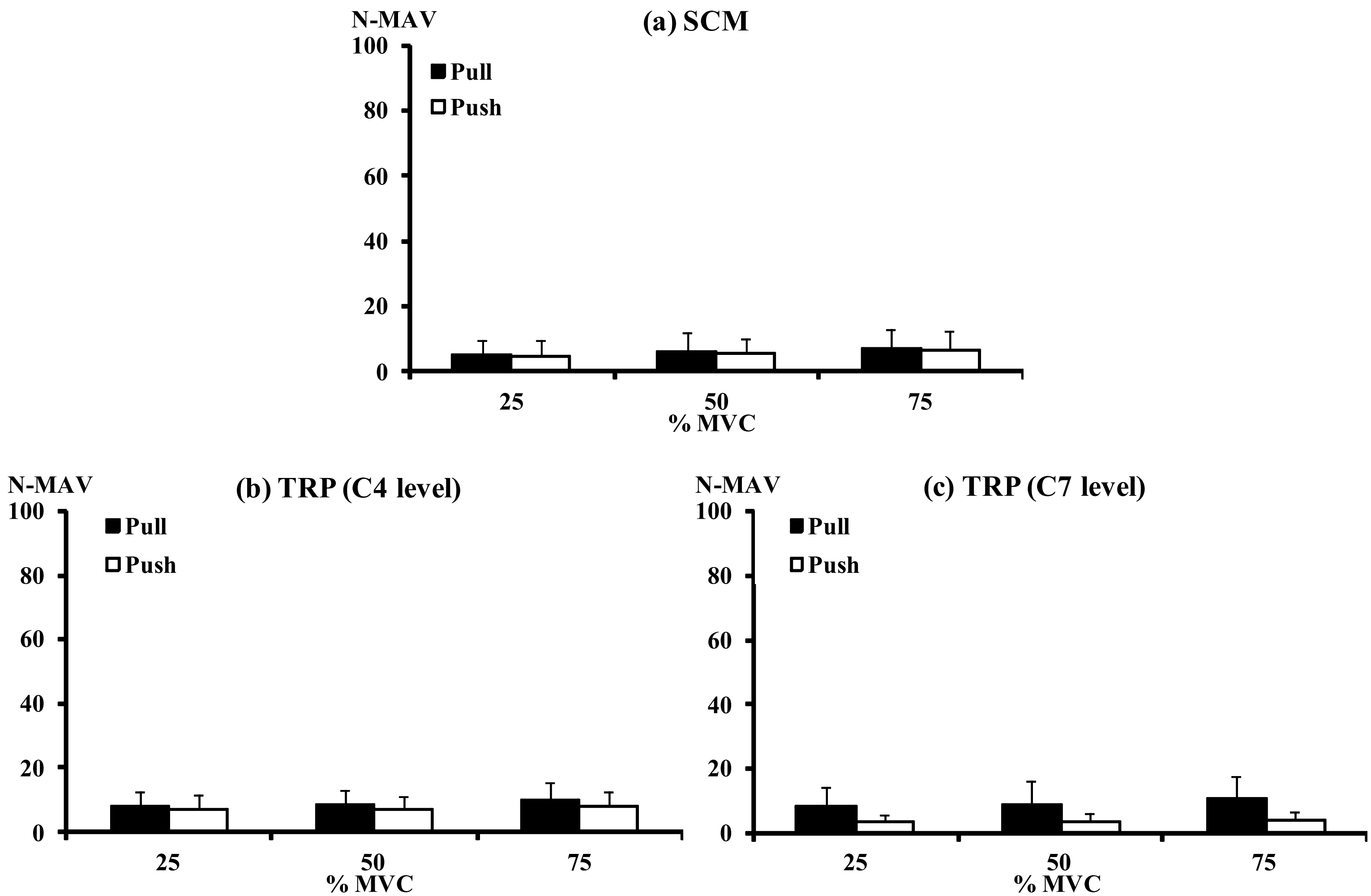


Figure 27: Behavior of the sternocleidomastoid (SCM) muscle (a) and the upper trapezius (TRP) muscle along C4 (b) and C7 (c) (N-MAV values) while participants pull and push 25%, 50%, and 75% of their maximum strengths at shoulder height with their neck in the neutral posture.

Table 11: N-EMG values (mean (SD)) for the sternocleidomastoid and upper trapezius muscles during pushing and pulling at shoulder height with neck in the neutral posture.

	Sternocleidomastoid	
	Direction of force application	
Weight	Pulling	Pushing
25%	(a)5.05 (4.35) (x)	(a)4.92 (4.54) (x)
50%	(a)6.05 (5.86) (xy)	(a)5.61 (4.70) (xy)
75%	(a)6.85 (5.87) (y)	(a)6.42 (6.08) (y)
	Upper trapezius (along the C4 level)	
25%	(a)8.25 (4.50) (x)	(a)7.19 (4.36) (x)
50%	(a)8.55 (4.33) (x)	(a)7.22 (4.18) (x)
75%	(a)9.99 (5.49) (y)	(b)8.27 (4.35) (x)
	Upper trapezius (along the C7 level)	
25%	(a)8.14 (6.37) (x)	(b)3.29 (2.26) (x)
50%	(a)8.52 (7.74) (x)	(b)3.37 (2.75) (x)
75%	(a)10.4 (7.42) (y)	(b)3.82 (2.97) (x)

The N-MAV data for the sternocleidomastoid muscle and the upper trapezius muscle along levels C4 and C7, while participants pulled 25%, 50%, and 75% of their maximum strengths at overhead heights in a neutral neck posture, is presented in Appendix F. The results of the statistical analysis (ANOVA tables and all-pairwise comparison test) are presented in Appendix G.

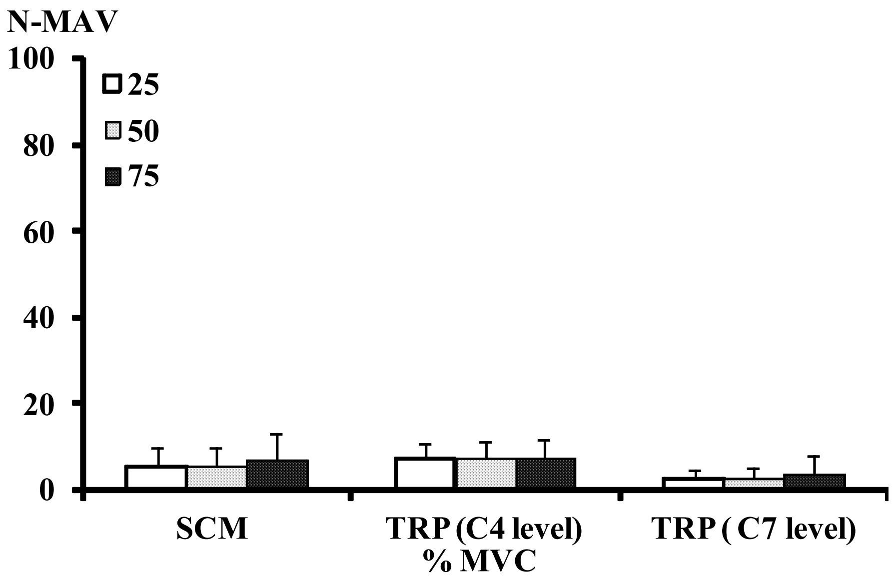


Figure 28: Behavior of the sternocleidomastoid (SCM) muscle and the upper trapezius (TRP) muscle along C4 and C7 (N-MAV values) while participants performing overhead pulling, exerting 25%, 50%, and 75% of their maximum strengths with their neck in the neutral posture.

Table 12: N-EMG values (mean (SD)) for the sternocleidomastoid and upper trapezius muscles during overhead pulling with neck in the neutral posture.

	Overhead pulling		
Weight	Sternocleidomastoid	Upper trapezius (along the C4 level)	Upper trapezius (along the C7 level)
25%	5.15 (4.66) (x)	6.88 (3.72) (x)	6.88 (3.72) (x)
50%	5.32 (4.35) (x)	7.17 (4.02) (xy)	7.17 (4.02) (x)
75%	6.93 (6.20) (y)	7.43 (4.22) (y)	7.43 (4.22) (x)

7.4 Section 2 - Comparison across the Tasks

7.4.1 Effect of Weights or Levels of Force Exertion

A comparison across the thirteen exertions, shows an increase in the weight or level of force exertion significantly affected the activation of the sternocleidomastoid muscle (F=77.20, $P<0.001$). A significant weight × tasks interaction was observed for sternocleidomastoid muscle activities (F=10.15, $P<0.001$). Based on the post hoc analysis, while lifting at the elbow height with the neck extended, the muscle activation at 75% weight condition was significantly higher than 25% and 50% weight conditions (Figure 29, Table 13). At shoulder height, muscle activation at 75% weight condition was significantly higher than at 25% and 50% weight conditions for all the neck postures (neutral, flexed, and extended). In addition to having the muscle activation at 75% weight condition significantly higher than the 25% and 50% weight conditions for all neck postures, at overhead heights, the muscle activation at 50% weight condition was higher than the 25% weight condition at extended and neutral neck posture. At shoulder and overhead heights, with the neck in flexed postures, increased muscle activation with the increase in the weight condition from 25% to 50% was statistically insignificant. Moreover during exertions such as lifting at knuckle height, lifting at elbow height in neutral and flexed neck posture, pushing and pulling at shoulder height, and overhead pulling, the activities of the sternocleidomastoid muscle increased with the increase in the weight lifted or force exerted, yet the values were statistically not significant.

An increase in the weight or level of force exertion significantly increased the activities of the upper trapezius muscle along C4 level, when compared across thirteen exertions (F=81.15, $P<0.001$). A significant weight × tasks interaction was observed for the activities of the upper trapezius muscle along the C4 level (F=14.48, $P<0.001$). While performing lifting at the elbow height, the muscle activities at 75% weight condition were higher than the respective 25% condition during all neck postures (Figure 30, Table 14). An increase in the muscle activation with the increase in the weights from 25% to 50% was statistically not significant. Lifting at shoulder heights significantly increased the muscle activation with the increase in the weight from 25% to 50% to 75% at neutral and flexed neck posture. At extended neck posture, the increase in the muscle activation was statistically significant only for the increase in weight from 25% to 75% and from 50% to 75%. At overhead heights as well, the increase in the muscle activation was statistically significant at neutral and flexed neck posture, for the increase in the weights from 25% to 50% to 75% and at the extended neck posture with the increase in the weight from 25% to 75% and from 50% to 75%. An increase in muscle activation with the increase in the weights or the level of force exertion was statistically insignificant during lifting at knuckle height, pushing and pulling at shoulder height, and overhead pulling.

The activities of the upper trapezius muscle along the C7 level also increased with an increase in the weight or level of force exertion, compared across thirteen exertions (F=111.21, $P<0.001$). A significant weight × tasks interaction was observed for the activities of the upper trapezius muscle along the C4 level (F=13.73, $P<0.001$). At knuckle height, increase in the muscle activation with the increase in weight was statistically not significant (Figure 30, Table 15). At elbow height, the muscle activation at 75% weight condition was significantly higher than the corresponding 25% weight conditions during all neck postures. An increase in the activation with an increase in the weight from 25% to 50% was statistically not significant. At shoulder and overhead

Table 13: Comparison of the N-EMG values for the sternocleidomastoid muscle between 25%, 50%, and 75% weights or force conditions during thirteen different types of exertions. The values marked with the different letters (x, y, and z) are statistically significant.

Direction of force	Lifting									
Lifting heights	Knuckle	Elbow	Elbow	Elbow	Shoulder	Shoulder	Shoulder	Overhead	Overhead	Overhead
Neck posture	Neut*	Ext*	Neut	Flx*	Ext	Neut	Flx	Ext	Neut	Flx
25%	3.89 $^{(x)}$ (3.35)	13.4 $^{(x)}$ (16.7)	3.14 $^{(x)}$ (2.65)	3.46$^{(x)}$ (3.34)	20.3 $^{(x)}$ (14.9)	4.20 $^{(x)}$ (3.04)	4.64 $^{(x)}$ (4.00)	24.9 $^{(x)}$ (20.9)	5.96 $^{(x)}$ (4.78)	6.38 $^{(x)}$ (5.97)
50%	4.16 $^{(x)}$ (3.51)	17.5$^{(x)}$ (20.2)	4.18$^{(x)}$ (3.17)	4.02$^{(x)}$ (2.88)	24.2$^{(x)}$ (19.9)	6.88$^{(x)}$ (4.84)	7.16$^{(x)}$ (5.19)	34.2$^{(y)}$ (26.7)	10.3$^{(y)}$ (7.97)	9.68$^{(x)}$ (8.39)
75%	5.02$^{(x)}$ (4.32)	22.1$^{(y)}$ (20.9)	6.15$^{(x)}$ (7.31)	5.88$^{(x)}$ (5.07)	30.8$^{(y)}$ (24.7)	9.81$^{(y)}$ (6.37)	11.0$^{(y)}$ (8.12)	40.4$^{(z)}$ (28.1)	16.6$^{(z)}$ (11.5)	16.1$^{(y)}$ (13.1)

Direction of force	Pulling	Pushing	Pulling	Pulling
Lifting heights	Shoulder	Shoulder	Overhead	Shoulder
Neck posture	Neut	Neut	Neut	Neut
25%	5.05 $^{(x)}$ (4.35)	4.92 $^{(x)}$ (4.54)	5.15 $^{(x)}$ (4.66)	5.05 $^{(x)}$ (4.35)
50%	6.05$^{(x)}$ (5.86)	5.61$^{(x)}$ (4.70)	5.32$^{(x)}$ (4.35)	6.05$^{(x)}$ (5.86)
75%	6.85$^{(x)}$ (5.87)	6.42$^{(x)}$ (6.08)	6.93 $^{(x)}$ (6.20)	6.85$^{(x)}$ (5.87)

(*Ext = extended neck posture; Neut = neutral neck posture; Flx=flexed neck posture)

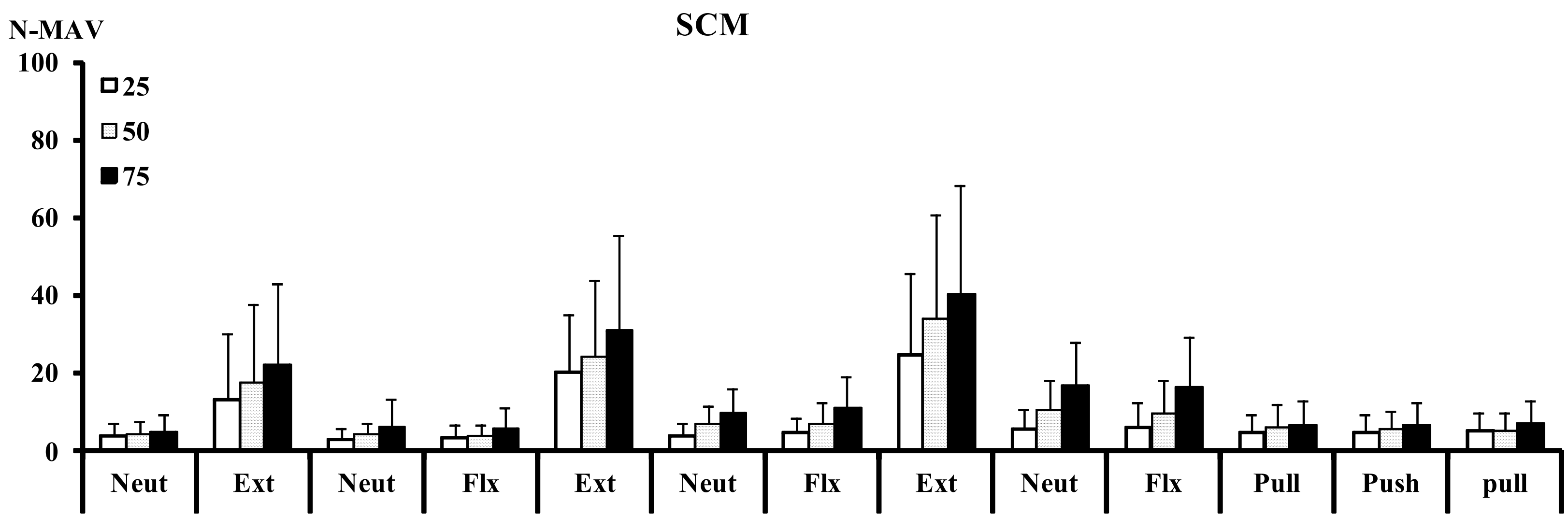


Figure 29: Effect of increase in the weights or level of forceful exertion (25%, 50%, and 75%) on the activities of the sternocleidomastoid muscle during different types of exertions at various heights and neck postures.

Table 14: Comparison of the N-EMG values for the upper trapezius (TRP) muscle between 25%, 50%, and 75% weights or force conditions during thirteen different types of exertions. The values marked with the different letters (x, y, and z) are statistically significant.

Direction of force	Lifting									
Lifting heights	Knuckle	Elbow	Elbow	Elbow	Shoulder	Shoulder	Shoulder	Overhead	Overhead	Overhead
Neck posture	Neut*	Ext*	Neut	Flx*	Ext	Neut	Flx	Ext	Neut	Flx
25%	9.15 $^{(x)}$ (4.10)	9.52 $^{(x)}$ (4.14)	10.8 $^{(x)}$ (5.58)	14.4 $^{(x)}$ (6.17)	16.4 $^{(x)}$ (8.48)	17.9 $^{(x)}$ (7.56)	23.7 $^{(x)}$ (12.6)	19.0 $^{(x)}$ (11.4)	17.8 $^{(x)}$ (8.07)	22.9 $^{(x)}$ (10.8)
50%	10.1 $^{(x)}$ (4.48)	14.8 $^{(xy)}$ (5.51)	15.8 $^{(xy)}$ (6.04)	18.8 $^{(xy)}$ (9.01)	23.7 $^{(x)}$ (14.3)	27.5 $^{(y)}$ (14.1)	35.5 $^{(y)}$ (18.4)	26.9 $^{(x)}$ (12.1)	29.0 $^{(y)}$ (18.9)	34.8 $^{(y)}$ (18.8)
75%	13.4 $^{(x)}$ (6.98)	20.8 $^{(y)}$ (7.40)	21.1 $^{(y)}$ (8.02)	26.4 $^{(y)}$ (9.94)	32.7 $^{(y)}$ (18.8)	35.9 $^{(z)}$ (21.1)	50.7 $^{(z)}$ (30.7)	40.1 $^{(y)}$ (27.7)	42.4 $^{(z)}$ (21.7)	53.6 $^{(z)}$ (34.5)

Direction of force	Pulling	Pushing	Pulling
Lifting heights	Shoulder	Shoulder	Overhead
Neck posture	Neut	Neut	Neut
25%	8.25 $^{(x)}$ (4.50)	7.19 $^{(x)}$ (4.36)	6.88 $^{(x)}$ (3.72)
50%	8.55 $^{(x)}$ (4.33)	7.22 $^{(x)}$ (4.18)	7.17 $^{(x)}$ (4.02)
75%	9.99 $^{(x)}$ (5.49)	8.27 $^{(x)}$ (4.35)	7.43 $^{(x)}$ (4.22)

(*Ext = extended neck posture; Neut = neutral neck posture; Flx=flexed neck posture)

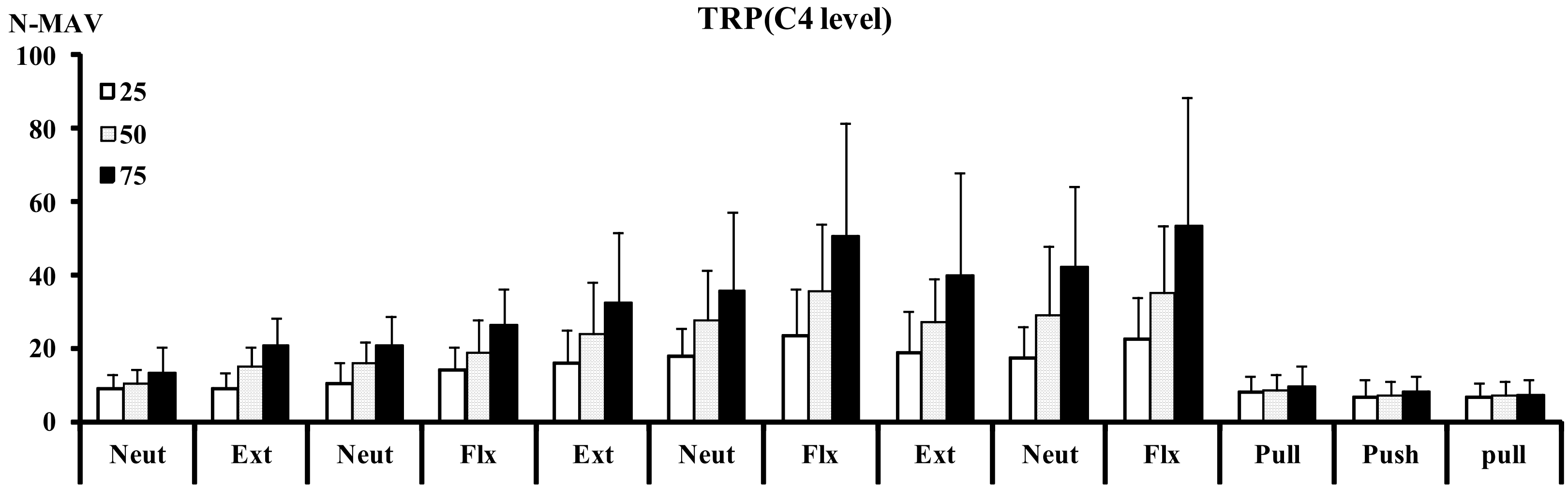


Figure 30: Effect of increase in the weights or levels of forceful exertion (25%, 50%, and 75%) on the activities of the upper trapezius (TRP) muscle along C4 level during different types of exertions at various heights and neck postures.

Table 15: Comparison of the N-EMG values for the upper trapezius (TRP) muscle between 25%, 50%, and 75% weights or force conditions during thirteen different types of exertions. The values marked with the different letters (x, y, and z) are statistically significant.

Direction of force	Lifting									
Lifting heights	Knuckle	Elbow	Elbow	Elbow	Shoulder	Shoulder	Shoulder	Overhead	Overhead	Overhead
Neck posture	Neut*	Ext*	Neut	Flx*	Ext	Neut	Flx	Ext	Neut	Flx
25%	7.62 (x) (4.85)	10.4 (x) (6.40)	11.4 (x) (7.21)	15.7 (x) (9.67)	23.5 (x) (15.2)	24.4 (x) (13.1)	29.4 (x) (18.5)	25.6 (x) (15.9)	25.0 (x) (15.0)	32.1 (x) (16.7)
50%	11.1 (x) (6.40)	18.2 (xy) (10.8)	19.4 (xy) (9.90)	23.0 (x) (12.4)	32.8 (y) (21.4)	36.2 (y) (22.3)	43.2 (y) (24.3)	36.1 (y) (19.9)	36.4 (y) (17.8)	46.3 (y) (24.3)
75%	15.5 (x) (9.10)	24.6 (y) (13.8)	25.4 (y) (15.2)	32.7 (y) (15.5)	44.7 (z) (30.5)	44.0 (y) (26.4)	57.6 (z) (36.2)	48.8 (z) (21.1)	50.9 (z) (22.0)	60.7 (z) (31.4)
Direction of force	Pulling	Pushing	Pulling							
Lifting heights	Shoulder	Shoulder	Overhead							
Neck posture	Neut	Neut	Neut							
25%	8.14 (x) (6.37)	3.29 (x) (2.26)	2.51 (x) (2.09)							
50%	8.52 (x) (7.74)	3.37 (x) (2.75)	2.61 (x) (2.75)							
75%	10.4 (x) (7.42)	3.82 (x) (2.97)	3.57 (x) (4.19)							

(*Ext = extended neck posture; Neut = neutral neck posture; Flx=flexed neck posture)

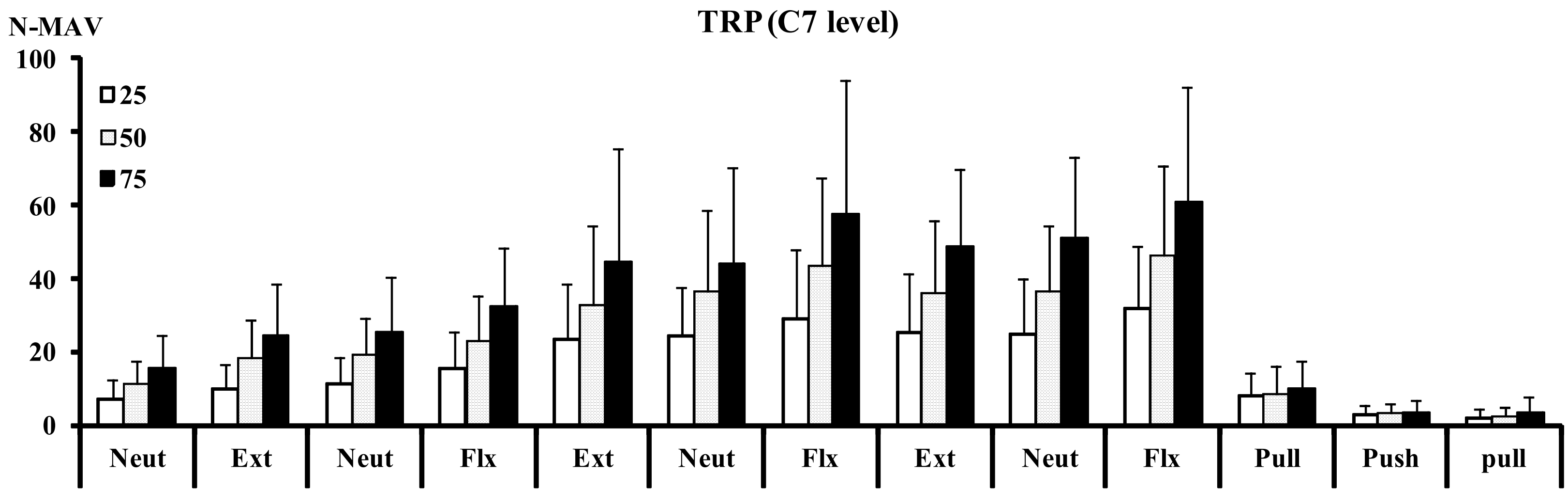


Figure 31: Effect of increase in the weights or level of forceful exertion (25%, 50%, and 75%) on the activities of the upper trapezius (TRP) muscle along C7 level during different types of exertions at various heights and neck postures.

heights, an increase in the weight from 25% to 50% to 75% significantly increased the muscle activation. Increase in the muscle activation with the increase in level of force exertion during pushing and pulling at shoulder height, and overhead pulling, was statistically not significant.

The results of the statistical analysis (ANOVA tables and all-pairwise comparison test) are presented in Appendix G.

7.4.2 Effect of Neck Posture

Neck postures significantly affected the activities of the neck muscles. The activities of the sternocleidomastoid muscle during lifting at elbow, shoulder, and overhead heights, were significantly affected by the change in the neck posture (F=40.07, $P<0.001$). A significant neck posture × tasks interaction (F=5.18, $P<0.001$) was observed for the sternocleidomastoid muscle. Based on the post hoc analysis, muscle activities while lifting 50% and 75% weights at the elbow height, with the neck in the extended posture, were significantly higher than during neutral and flexed neck postures (Figure 32, Table 16). At 25% weight conditions, the increase in muscle activities with a change in the neck posture from neutral to extended and from flexed to extended were statistically not significant. At shoulder and overhead heights, muscle activities increased significantly with a change in the neck posture from neutral to extended and from flexed to extended at all the weight conditions, i.e., 25%, 50%, and 75%. In general, the change in neck posture from neutral to flexed slightly reduced the activities of the sternocleidomastoid muscle during most of the lifting trials; however, the change was statistically not significant.

The neck posture also significantly affected the activities of the upper trapezius muscle along C4 ($F=24.25$, $P<0.001$) and C7 ($F=33.97$, $P<0.001$) during the performance of lifting tasks at elbow, shoulder, and overhead heights. A significant neck posture × tasks interaction was also observed for the activities of the upper trapezius muscle along levels C4 ($F=3.99$, $P<0.001$) and C7 ($F=1.76$, $P<0.03$). Statistically along the C4 level, at shoulder and overhead heights and while lifting 75% weights, the muscle activities were significantly higher at flexed neck posture than at neutral and extended neck postures (Figure 33, Table 17). At shoulder height, in addition to the 75% weight condition and while lifting 50% weights also, the muscle activities were found to be higher during flexed neck posture, compared to extended neck posture. Along the C7 level, the increase in the muscle activities with the change in the neck posture from extended to flexed and from neutral to flexed was statistically significant when lifting 75% weights at shoulder heights (Figure 34, Table 18) and 50% and 75% weight conditions at overhead heights. Generally, during all the remaining exertions, and at any weight condition, the upper trapezius muscle worked hardest at a flexed neck posture, followed by the neutral and flexed neck postures; however, the changes were statistically not significant.

The results of the statistical analysis (ANOVA tables and all-pairwise comparison test) are presented in Appendix G.

7.4.3 Effect of Lifting Height

In addition to the weights and neck posture, the activities of the neck muscles were also affected by the lifting heights. In general, independent of the neck postures and weight conditions, the neck muscles worked hardest at the overhead height, followed by the shoulder and elbow heights. The activation level at the elbow and knuckle heights

Table 16: Comparison of the N-EMG values for the sternocleidomastoid muscle across extended, neutral, and flexed neck postures at elbow, shoulder and overhead heights while lifting 25%, 50%, and 75% weights. The values marked with the different letters (x, y, and z for weight conditions and a, b, and c for neck postures) are statistically significant.

	Lifting at elbow ht.			Lifting at shoulder ht.			Lifting at Overhead ht.		
% MVC	25%	50%	75%	25%	50%	75%	25%	50%	75%
Extension	13.4 (x) (a)(16.7)	17.5 (x) (a) (20.2)	22.1 (y) (a) (20.9)	20.3 (x) (a) (14.9)	24.2 (x) (a) (19.9)	30.8 (y) (a) (24.7)	24.9 (x) (a) (20.9)	34.2 (y) (a) (26.7)	40.4 (z) (a) (28.1)
Neutral	3.14 (x) (a) (2.65)	4.18 (x) (b) (3.17)	6.15 (x) (b) (7.31)	3.04 (x) (b) (13.1)	4.84 (x) (b) (22.3)	6.37 (y) (b) (26.4)	5.96 (x) (b) (4.78)	10.3 (y) (b) (7.97)	16.6 (z) (b) (11.5)
Flexion	3.46 (x) (a) (3.34)	4.02 (x) (b) (2.88)	5.88 (x) (b) (5.07)	4.64 (x) (b) (4.00)	7.16 (x) (b) (5.19)	11.0 (y) (b) (8.12)	6.38 (x) (b) (5.97)	9.68 (x) (b) (8.39)	16.1 (y) (b) (13.1)

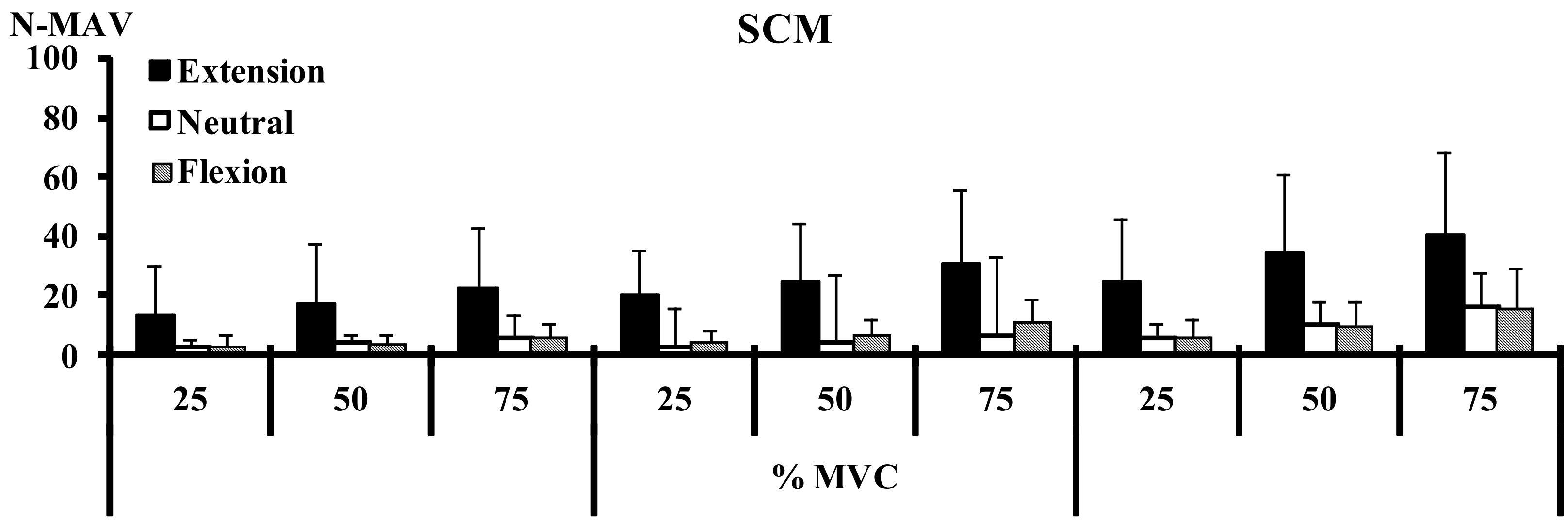


Figure 32: Effect of neck posture (extended, neutral, and flexed) on the activities of sternocleidomastoid (SCM) muscle while lifting 25%, 50%, and 75% weights at elbow, shoulder, and overhead heights.

Table 17: Comparison of the N-EMG values for the upper trapezius muscle along C4 level across extended, neutral, and flexed neck postures at elbow, shoulder, and overhead heights while lifting 25%, 50%, and 75% weights. The values marked with the different letters (x, y, and z for weight conditions and a, b, and c for neck postures) are statistically significant.

	Lifting at elbow ht.			Lifting at shoulder ht.			Lifting at Overhead ht.		
% MVC	25%	50%	75%	25%	50%	75%	25%	50%	75%
Extension	9.52 (x) (a)(4.14)	14.8 (xy) (a) (5.51)	20.8(y) (a) (7.40)	16.4(x) (a) (8.48)	23.7 (x) (a)(14.3)	32.7(y) (a) (18.8)	19.0 (x) (a)(11.4)	26.9 (x) (a)(12.1)	40.1 (y) (a) (27.7)
Neutral	10.8(x) (a) (5.58)	15.8(xy) (a) (6.04)	21.1(y) (a) (8.02)	17.9(x) (a) (7.56)	27.5 (y) (a)(14.1)	35.9 (z) (a) (21.1)	17.8 (x) (a)(8.07)	29.0 (y) (a)(18.9)	42.4 (z) (a)(21.7)
Flexion	14.4(x) (a) (6.17)	18.8 (xy) (a) (9.01)	26.4 (y) (a) (9.94)	23.7 (x) (a) (12.6)	35.5 (y) (b)(18.4)	50.7 (z) (b) (30.7)	22.9 (x) (a)(10.8)	34.8 (y) (a)(18.8)	53.6 (z) (b)(34.5)

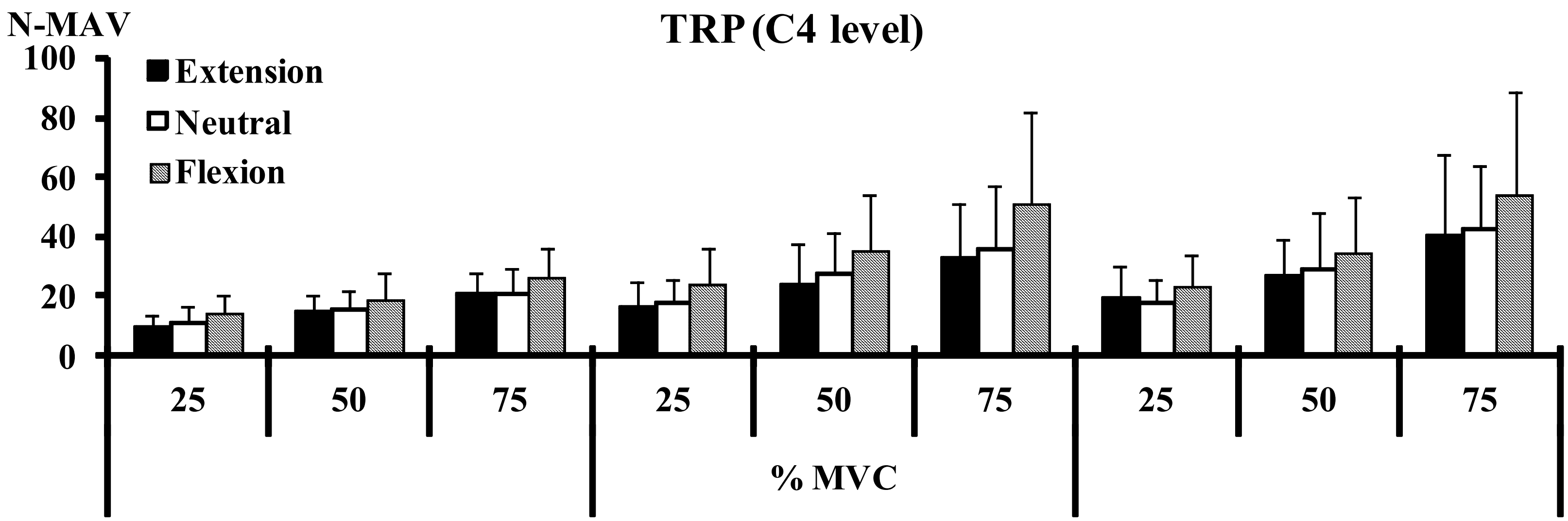


Figure 33: Effect of neck posture (extended, neutral, and flexed) on the activities of the upper trapezius (TRP) muscle along C4 while lifting 25%, 50%, and 75% weights at elbow, shoulder, and overhead heights.

Table 18: Comparison of the N-EMG values for the upper trapezius muscle along C7 level across extended, neutral, and flexed neck postures at elbow, shoulder, and overhead heights while lifting 25%, 50%, and 75% weights. The values marked with the different letters (x, y, and z for weight conditions and a, b, and c for neck postures) are statistically significant.

	Lifting at elbow ht.			Lifting at shoulder ht.			Lifting at Overhead ht.		
% MVC	25%	50%	75%	25%	50%	75%	25%	50%	75%
Extension	10.4 (x) (a)(6.40)	18.2 (xy) (a) (10.8)	24.6 (y) (a) (13.8)	23.5(x) (a) (15.2)	32.8(y) (a) (21.4)	44.7 (z) (a) (30.5)	25.6 (x) (a) (15.9)	36.1 (y) (a) (19.9)	48.8(z) (a) (21.1)
Neutral	11.4(x) (a) (7.21)	19.4 (xy) (a) (9.90)	25.4(y) (a) (15.2)	24.4(x) (a) (13.1)	36.2 (y) (a) (22.3)	44.0(y) (a) (26.4)	25.0(x) (a) (15.0)	36.4 (y) (a) (17.8)	50.9(z) (a) (22.0)
Flexion	15.7 (x) (a) (9.67)	23.0 (x) (a) (12.4)	32.7(y) (a) (15.5)	29.4 (x) (a) (18.5)	43.2 (y) (a) (24.3)	57.6(z) (b) (36.2)	32.1(x) (a) (16.7)	46.3 (y) (b) (24.3)	60.7 (z) (b) (31.4)

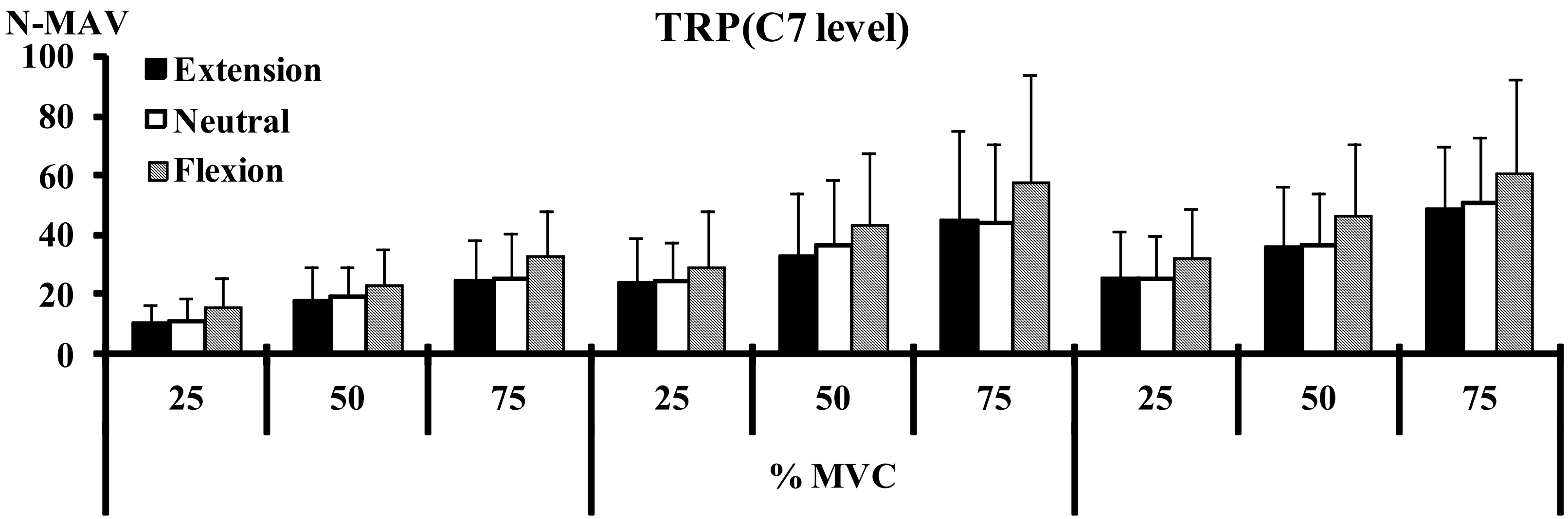


Figure 34: Effect of neck posture (extended, neutral, and flexed) on the activities of the upper trapezius muscle along C7 while lifting 25%, 50%, and 75% weights at elbow, shoulder, and overhead height

was almost identical. Statistically, the activities of the sternocleidomastoid muscle increased significantly with the increase in the lifting heights from knuckle to elbow to shoulder to overhead (F=29.49, *P<0.001*). Based on the post hoc analysis, at neutral and flexed neck posture and during 25% and 50% weight conditions, the increase in the muscle activities, together with the increase in lifting heights from elbow to shoulder to overhead, was statistically not significant (Figure 35, Table 19). At 75% weight conditions, the muscle activities at the overhead heights were significantly higher than at elbow height. At the extended neck posture during 25%, 50%, and 75% weight conditions, the muscle activities at the overhead height were statistically higher than at the elbow height. The exertions during which the muscle activities at the overhead height were statistically higher than at the elbow height, showed an increase in the muscle activities with the increase in height from elbow to shoulder and from shoulder to overhead, yet the increase was statistically insignificant.

An increase in lifting heights also increased the activation of the upper trapezius muscle along C4 (F=29.64, *P<0.001*) and C7 (F=42.89, *P<0.001*) levels. Based on the post hoc analysis, at 25% weight condition, an increase in the activities of the upper trapezius muscle along the C4 level during all the neck postures, was statistically insignificant (Figure 36, Table 20). At 50% weight condition, at the neutral and flexed neck posture, the muscle activities increased significantly with the change in the lifting height from elbow to shoulder and from elbow to overhead. The extended neck posture was significant in the change in lifting height from elbow to overhead. At 50% and 75% weight conditions during all neck postures, an increase in muscle activities with the change in lifting height from shoulder to overhead, was statistically insignificant.

Table 19: Comparison of the N-EMG values for the sternocleidomastoid muscle across various lifting heights at 25%, 50%, and 75% weight conditions in extended, neutral, and flexed neck postures. The values marked with the different letters (x, y, and z for weight conditions; a,b, and c for neck postures; I, II, and III for lifting heights) are statistically significant.

%MVC	25			50		
Neck Posture	Ext*	Neut*	Flx*	Ext	Neut	Flx
Knuckle		3.89$^{(x)}$ (3.35)$_{(I)}$			4.16$^{(x)}$ (3.51)$_{(I)}$	
Elbow	13.4$^{(x)}$ $_{(a)}$(16.7)$_{(I)}$	3.14$^{(x)}$ $_{(a)}$ (2.65)$_{(I)}$	3.46$^{(x)}$ $_{(a)}$ (3.34)$_{(I)}$	17.5$^{(x)}$ $_{(a)}$ (20.2)$_{(I)}$	4.18$^{(x)}$ $_{(b)}$ (3.17)$_{(I)}$	4.02$^{(x)}$ $_{(b)}$ (2.88)$_{(I)}$
Shoulder	20.3$^{(x)}$ $_{(a)}$ (14.9)$_{(I\ II)}$	4.20$^{(x)}$ $_{(b)}$ (3.04)$_{(I)}$	4.64$^{(x)}$ $_{(b)}$ (4.00)$_{(I)}$	24.2$^{(x)}$ $_{(a)}$ (19.9)$_{(I\ II)}$	6.88$^{(x)}$ $_{(b)}$ (4.84)$_{(I)}$	7.16$^{(x)}$ $_{(b)}$ (5.19)$_{(I)}$
Overhead	24.9$^{(x)}$ $_{(a)}$ (20.9)$_{(II)}$	5.96$^{(x)}$ $_{(b)}$ (4.78)$_{(I)}$	6.38$^{(x)}$ $_{(b)}$(5.97)$_{(I)}$	34.2$^{(y)}$ $_{(a)}$ (26.7)$_{(II)}$	10.3$^{(y)}$ $_{(b)}$ (7.97)$_{(I)}$	9.68$^{(x)}$ $_{(b)}$ (8.39)$_{(I)}$

%MVC	75		
Neck Posture	Ext	Neut	Flx
Knuckle		5.02$^{(x)}$ (4.32)$_{(I)}$	
Elbow	22.1$^{(y)}$ $_{(a)}$ (20.9)$_{(I)}$	6.15$^{(x)}$ $_{(b)}$ (7.31)$_{(I)}$	5.88$^{(x)}$ $_{(a)}$ (5.07)$_{(I)}$
Shoulder	30.8$^{(y)}$ $_{(a)}$ (24.7)$_{(I\ II)}$	9.81$^{(y)}$ $_{(b)}$ (6.37)$_{(I\ II)}$	11.0$^{(x)}$ $_{(a)}$ (8.12)$_{(I)}$
Overhead	40.4$^{(z)}$ $_{(a)}$ (28.1)$_{(II\ II)}$	16.6$^{(z)}$ $_{(b)}$ (11.5)$_{(II\ II)}$	16.1$^{(x)}$ $_{(a)}$(13.1)$_{(I)}$

(*Ext = extended neck posture; Neut = neutral neck posture; Flx=flexed neck posture)

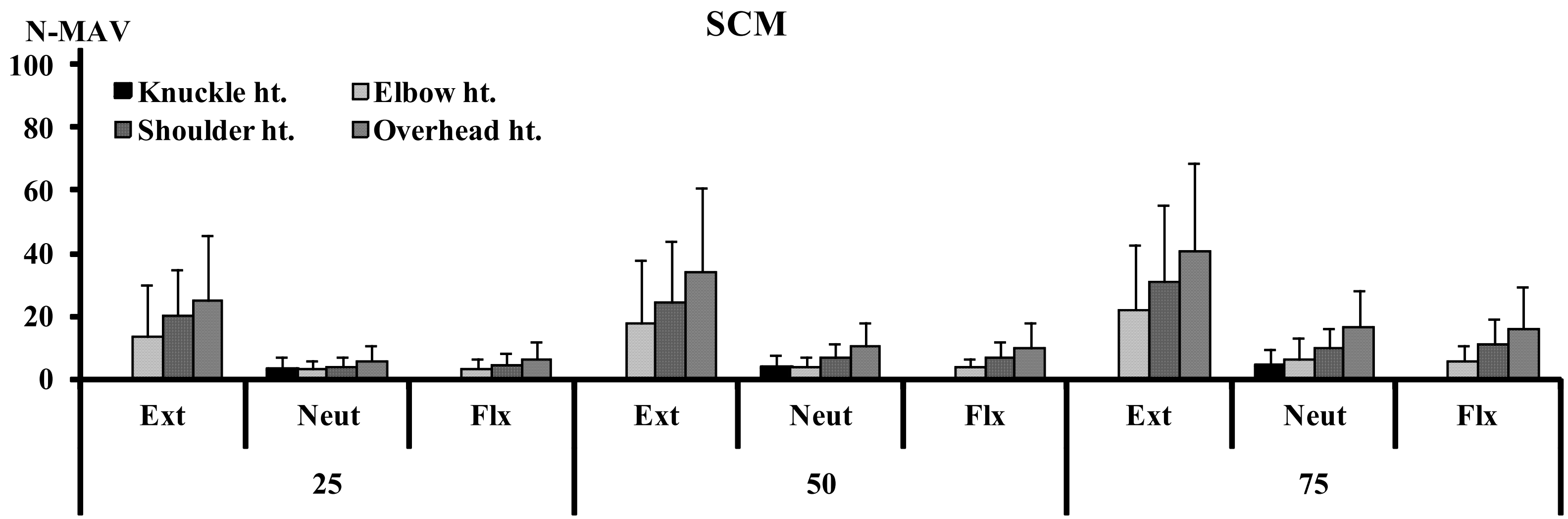


Figure 35: Effect of lifting heights (knuckle, elbow, shoulder, and overhead) on the activities of the sternocleidomastoid (SCM) muscle while lifting 25%, 50%, and 75% weights in neutral, flexed, and extended neck postures.

Table 20: Comparison of the N-EMG values for the upper trapezius muscle along C4 level across various lifting heights at 25%, 50%, and 75% weight conditions in extended, neutral, and flexed neck postures. The values marked with the different letters (x, y, and z for weight conditions; a,b, and c for neck postures; I, II, and III for lifting heights) are statistically significant.

%MVC	25			50			75		
Neck Posture	Ext*	Neut*	Flx*	Ext	Neut	Flx	Ext	Neut	Flx
Knuckle		$9.15^{(x)}$ $(4.10)_{(I)}$			$10.1^{(x)}$ $(4.48)_{(I)}$			$13.4^{(x)}$ $(6.98)_{(I)}$	
Elbow	$9.52^{(x)}$ $_{(a)}(4.14)_{(I)}$	$10.8^{(x)}$ $_{(a)}(5.58)_{(I)}$	$14.4^{(x)}$ $_{(a)}(6.17)_{(I)}$	$14.8^{(xy)}$ $_{(a)}(5.51)_{(I)}$	$15.8^{(xy)}$ $_{(a)}(6.04)_{(I)}$	$18.8^{(xy)}$ $_{(a)}(9.01)_{(I)}$	$20.8^{(y)}$ $_{(a)}(7.40)_{(I)}$	$21.1^{(y)}$ $_{(a)}(8.02)_{(I)}$	$26.4^{(y)}$ $_{(a)}(9.94)_{(I)}$
Shoulder	$16.4^{(x)}$ $_{(a)}(8.48)_{(I)}$	$17.9^{(x)}$ $_{(a)}(7.56)_{(I)}$	$23.7^{(x)}$ $_{(a)}(12.6)_{(I)}$	$23.7^{(x)}$ $_{(a)}(14.3)_{(I\ II)}$	$27.5^{(y)}$ $_{(a)}(14.1)_{(II)}$	$35.5^{(y)}$ $_{(b)}(18.4)_{(II)}$	$32.7^{(y)}$ $_{(a)}(18.8)_{(II)}$	$35.9^{(z)}$ $_{(a)}(21.1)_{(II)}$	$50.7^{(z)}$ $_{(b)}(30.7)_{(II)}$
Overhead	$19.0^{(x)}$ $_{(a)}(11.4)_{(I)}$	$17.8^{(x)}$ $_{(a)}(8.07)_{(I)}$	$22.9^{(x)}$ $_{(a)}(10.8)_{(I)}$	$26.9^{(x)}$ $_{(a)}(12.1)_{(II)}$	$29.0^{(y)}$ $_{(a)}(18.9)_{(II)}$	$34.8^{(y)}$ $_{(a)}(18.8)_{(II)}$	$40.1^{(y)}$ $_{(a)}(27.7)_{(II)}$	$42.4^{(z)}$ $_{(a)}(21.7)_{(II)}$	$53.6^{(z)}$ $_{(b)}(34.5)_{(II)}$

(*Ext = extended neck posture; Neut = neutral neck posture; Flx=flexed neck posture)

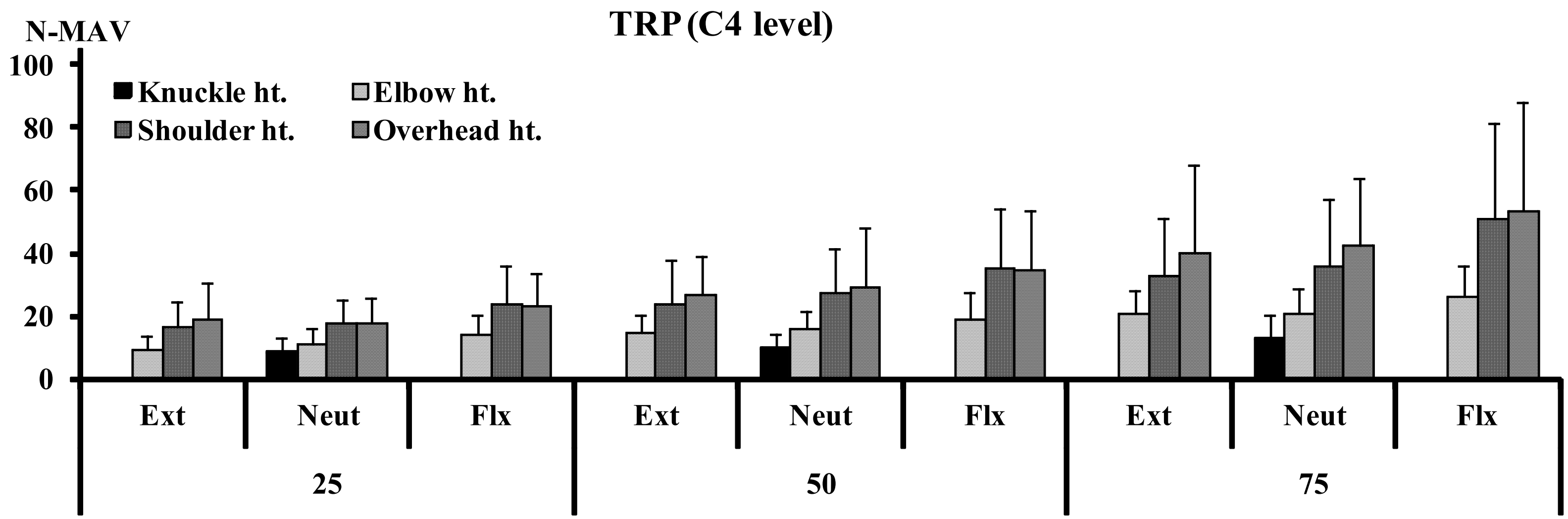


Figure 36: Effect of lifting heights (knuckle, elbow, shoulder, and overhead) on the activities of the upper trapezius (TRP) muscle along C4 while lifting 25%, 50%, and 75% weights in neutral, flexed, and extended neck postures.

Table 21: Comparison of the N-EMG values for the upper trapezius muscle along C7 level across various lifting heights at 25%, 50%, and 75% weight conditions in extended, neutral, and flexed neck postures. The values marked with the different letters (x, y, and z for weight conditions; a,b, and c for neck postures; I, II, and III for lifting heights) are statistically significant.

%MVC	25			50			75		
Neck Posture	Ext*	Neut*	Flx*	Ext	Neut	Flx	Ext	Neut	Flx
Knuckle		7.62 $^{(x)}$ (4.85) $_{(I)}$			11.1 $^{(x)}$ (6.40) $_{(I)}$			15.5 $^{(x)}$ (9.10) $_{(I)}$	
Elbow	10.4 $^{(x)}$ $_{(a)}$ (6.40) $_{(I)}$	11.4 $^{(x)}$ $_{(a)}$ (7.21) $_{(I)}$	15.7 $^{(x)}$ $_{(a)}$ (9.67) $_{(I)}$	18.2 $^{(xy)}$ $_{(a)}$ (10.8) $_{(I)}$	19.4 $^{(xy)}$ $_{(a)}$ (9.90) $_{(I)}$	23.0 $^{(x)}$ $_{(a)}$ (12.4) $_{(I)}$	24.6 $^{(y)}$ $_{(a)}$ (13.8) $_{(I)}$	25.4 $^{(y)}$ $_{(a)}$ (15.2) $_{(I)}$	32.7 $^{(y)}$ $_{(a)}$ (15.5) $_{(I)}$
Shoulder	23.5 $^{(x)}$ $_{(a)}$ (15.2) $_{(II)}$	24.4 $^{(x)}$ $_{(a)}$ (13.1) $_{(II)}$	29.4 $^{(x)}$ $_{(a)}$ (18.5) $_{(II)}$	32.8 $^{(y)}$ $_{(a)}$ (21.4) $_{(II)}$	36.2 $^{(y)}$ $_{(a)}$ (22.3) $_{(II)}$	43.2 $^{(y)}$ $_{(a)}$ (24.3) $_{(II)}$	44.7 $^{(z)}$ $_{(a)}$ (30.5) $_{(II)}$	44.0 $^{(y)}$ $_{(a)}$ (26.4) $_{(II)}$	57.6 $^{(z)}$ $_{(b)}$ (36.2) $_{(II)}$
Overhead	25.6 $^{(x)}$ $_{(a)}$ (15.9) $_{(II)}$	25.0 $^{(x)}$ $_{(a)}$ (15.0) $_{(II)}$	32.1 $^{(x)}$ $_{(a)}$ (16.7) $_{(II)}$	36.1 $^{(y)}$ $_{(a)}$ (19.9) $_{(II)}$	36.4 $^{(y)}$ $_{(a)}$ (17.8) $_{(II)}$	46.3 $^{(y)}$ $_{(b)}$ (24.3) $_{(II)}$	48.8 $^{(z)}$ $_{(a)}$ (21.1) $_{(II)}$	50.9 $^{(z)}$ $_{(a)}$ (22.0) $_{(II)}$	60.7 $^{(z)}$ $_{(b)}$ (31.4) $_{(II)}$

(*Ext = extended neck posture; Neut = neutral neck posture; Flx=flexed neck posture)

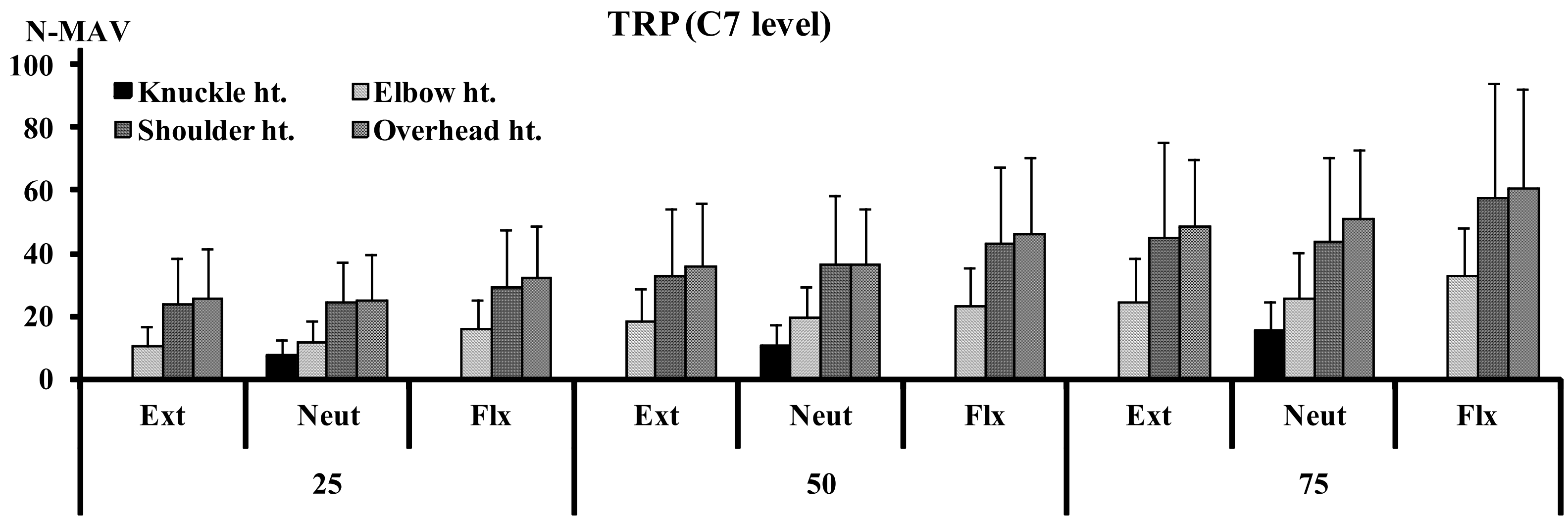


Figure 37: Effect of lifting heights (knuckle, elbow, shoulder, and overhead) on the activities of the upper trapezius (TRP) muscle along C7 while lifting 25%, 50%, and 75% weights in neutral, flexed, and extended neck postures.

For the upper trapezius muscle along the C7 level at 25%, 50% and 75% weight conditions during all neck postures, the increase in the muscle activities with the change in lifting height from elbow to shoulder and from elbow to overhead was statistically significant (Figure 37, Table 21). However, the increase in the muscle activities with the change in the lifting height from shoulder to overhead was statistically insignificant. The results of the statistical analysis (ANOVA tables and all-pairwise comparison test) are presented in the Appendix G.

Table 22: N-EMG values for the sternocleidomastoid muscle during lifting, pulling, and pushing at 25%, 50%, and 75% weight conditions in neutral neck posture. The values marked with the different letters (μ and β different force exertion directions) are statistically significant.

	Shoulder ht.			Overhead ht.		
% MVC	25	50	75	25	50	75
Lifting	4.20 (x) (3.04) μ	6.88 (x) (4.84) μ	9.81 (y) (6.37) μ	5.96 (x) (4.78) μ	10.3 (y) (7.97) μ	16.6 (z) (11.5) μ
Pulling	5.05 (x) (4.35) μ	6.05 (x) (5.86) μ	6.85 (x) (5.87) μ	5.15 (x) (4.66) μ	5.32 (x) (4.35) β	6.93 (x) (6.20) β
Pushing	4.92 (x) (4.54) μ	5.61 (x) (4.70) μ	6.42 (x) (6.08) μ			

7.4.4 Effect of Direction of Force Application

The direction of force application (e.g., lifting, pulling, and pushing) had a significant effect on the activation of the neck muscles. For the sternocleidomastoid muscle at shoulder height, change in the direction of force application from lifting to pulling to pushing, and at overhead heights from lifting to pulling significantly affected the muscle activities (F=11.89, P<0.001). At shoulder height, the muscle was most active during lifting, followed by pulling and pushing (Figure 38, Table 22). At overhead height, muscle activity during lifting was higher than during pulling. Based on the post hoc analysis, at overhead heights the muscle activities during lifting were significantly higher than during pulling for 50% and 75% weight conditions. Statistically, no difference was found in the muscle activities during lifting, pushing, and pulling at shoulder height.

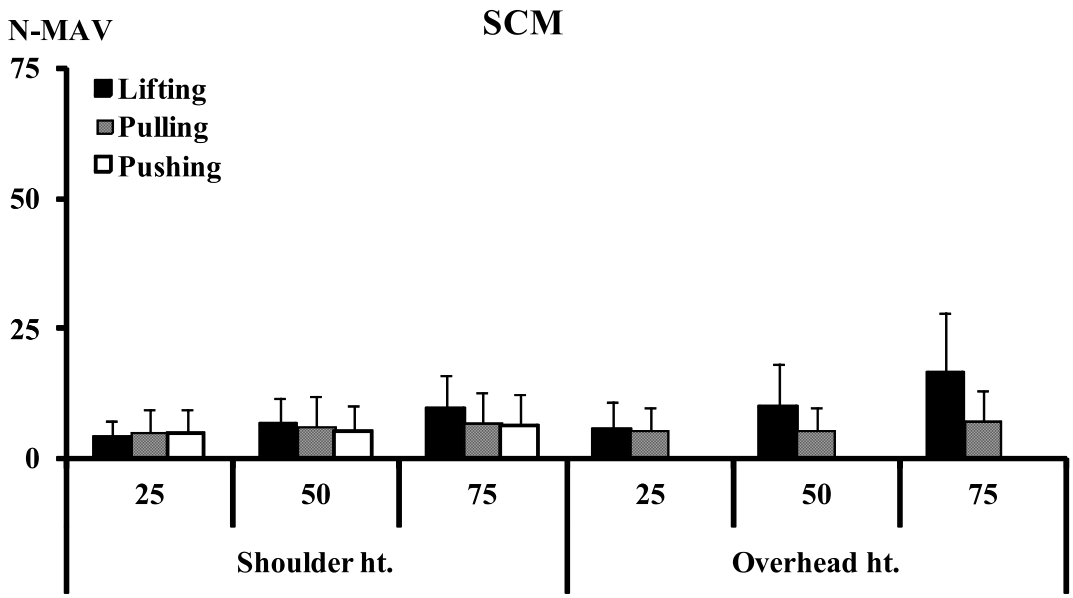


Figure 38: Behavior of the sternocleidomastoid (SCM) muscle during lifting, pulling, and pushing at 25%, 50%, and 75% weight conditions in neutral neck posture.

Table 23: N-EMG values for the upper trapezius muscle along C4 during lifting, pulling, and pushing at 25%, 50%, and 75% weight conditions in neutral neck posture. The values marked with the different letters (Ψ and β different force exertion directions) are statistically significant.

	Shoulder ht.			Overhead ht.		
% MVC	25	50	75	25	50	75
Lifting	17.9 $^{(x)}$ (7.56)$_{\mu}$	27.5 $^{(y)}$ (14.1) $_{\mu}$	35.9 $^{(z)}$ (21.1) $_{\mu}$	17.8 $^{(x)}$ (8.07) $_{\mu}$	29.0 $^{(y)}$ (18.9) $_{\mu}$	42.4 $^{(z)}$ (21.7) $_{\mu}$
Pulling	8.25$^{(x)}$ (4.50)$_{\beta}$	8.55 $^{(x)}$ (4.33) $_{\beta}$	9.99 $^{(x)}$ (5.49) $_{\beta}$	6.88 $^{(x)}$ (3.72) $_{\beta}$	7.17 $^{(x)}$ (4.02) $_{\beta}$	7.43 $^{(x)}$ (4.22) $_{\beta}$
Pushing	7.19 $^{(x)}$ (4.36) $_{\beta}$	7.22 $^{(x)}$ (4.18) $_{\beta}$	8.27 $^{(x)}$ (4.35) $_{\beta}$			

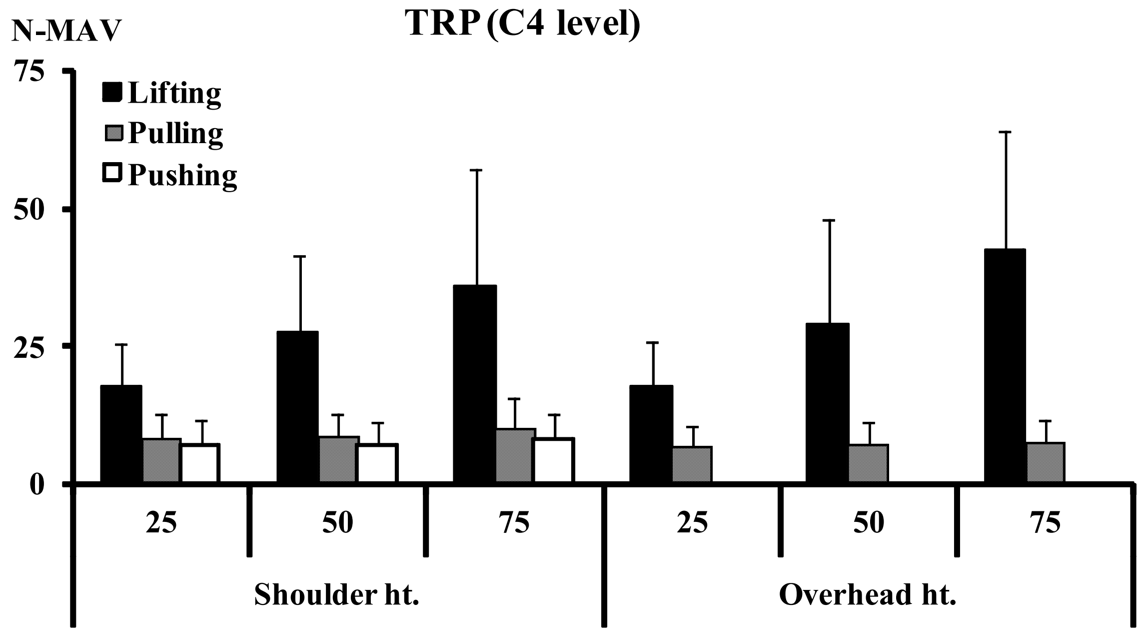


Figure 39: Behavior of the upper trapezius (TRP) muscle along C4 during lifting, pulling, and pushing at 25%, 50%, and 75% weight conditions in neutral neck posture.

Table 24: N-EMG values for the upper trapezius muscle along C7 during lifting, pulling, and pushing at 25%, 50%, and 75% weight conditions in neutral neck posture. The values marked with the different letters (Ψ and β different force exertion directions) are statistically significant.

	Shoulder ht.			Overhead ht.		
% MVC	25	50	75	25	50	75
Lifting	24.4 (x) (13.1) $_{\mu}$	36.2 (x) (22.3) $_{\mu}$	44.0 (y) (26.4) $_{\mu}$	25.0 (x) (15.0) $_{\mu}$	36.4 (y) (17.8) $_{\mu}$	50.9 (z) (22.0) $_{\mu}$
Pulling	8.14 (x) (6.37) $_{\beta}$	8.52 (x) (7.74) $_{\beta}$	10.4 (x) (7.42) $_{\beta}$	2.51 (x) (2.09) $_{\beta}$	2.61 (x) (2.75) $_{\beta}$	3.57 (x) (4.19) $_{\beta}$
Pushing	3.29 (x) (2.26) $_{\beta}$	3.37 (x) (2.75) $_{\beta}$	3.82 (x) (2.97) $_{\beta}$			

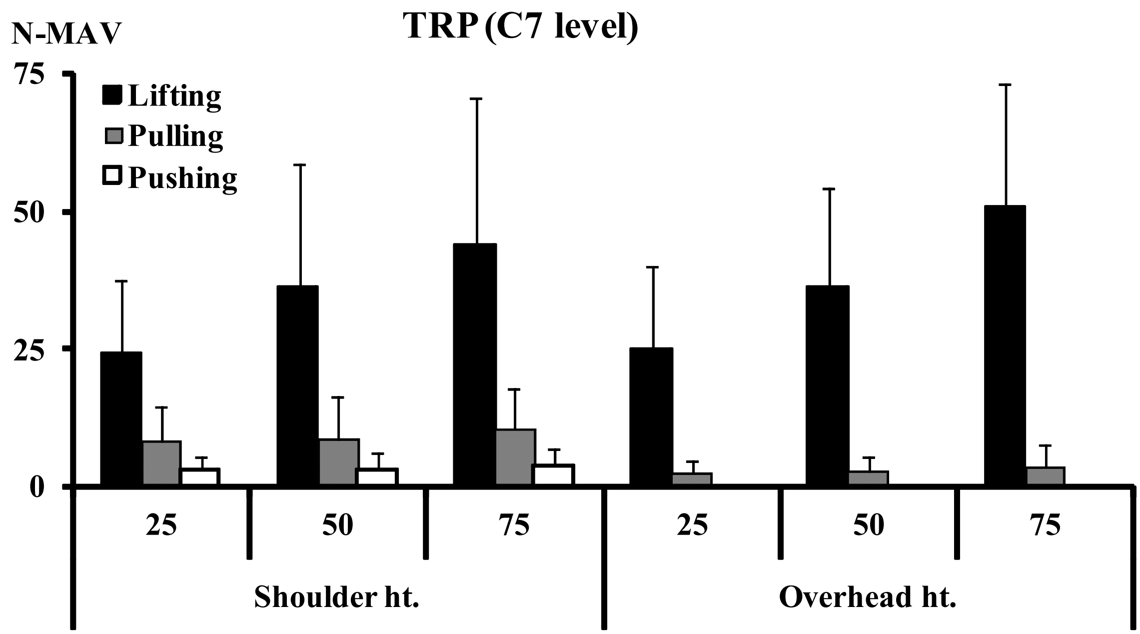


Figure 40: Behavior of the upper trapezius (TRP) muscle along C7 during lifting, pulling, and pushing at 25%, 50%, and 75% weight conditions in neutral neck posture.

The activities of the upper trapezius muscle along the C4 (F=59.54, P<0.001) and C7 (F=94.49, P<0.001) levels were also significantly affected by the direction of force application. Based on the post hoc analysis, for both muscle locations, at shoulder height during all the weight conditions, muscle activation during lifting was significantly higher than during pulling and pushing (Figure 39, Figure 40, Table 23,Table 24). While at the overhead height, muscle activation during lifting was significantly higher than during pulling. The results of the statistical analysis (ANOVA tables and all-pairwise comparison test) are presented in Appendix G.

7.5 Section 3 - Gender Difference

Gender had significant effect on the activities of the sternocleidomastoid (F=5.27 P=0.0293) muscle. In general the activities of the muscle for female participants were higher than for the male participants (Table 25). During all the exertions, on an average for female participants, the sternocleidomastoid muscle worked 43% harder than for the male participants.

Table 25: N-EMG values for the sternocleidomastoid muscle for the male and female participants

		25		50		75	
	Neck posture	Male	Female	Male	Female	Male	Female
Knuckle ht.	Neut	3.06(2.41)	5.42(5.07)	3.07(2.71)	6.03(5.19)	4.28(4.17)	6.61(5.82)
Elbow ht.	Ext	9.36(9.47)	21.6(26.8)	12.9(14.3)	29.3(30.5)	18.3(21.7)	32.1(30.4)
	Neut	2.95(3.17)	4.82(5.00)	3.78(4.06)	6.22(5.02)	5.13(5.88)	9.23(10.3)
	Flx	3.39(4.27)	5.29(6.39)	4.67(6.23)	5.56(5.29)	5.97(7.34)	8.63(8.69)
Shoulder ht.	Ext	25.5(28.2)	28.2(23.2)	27.8(38.6)	36.4(32.8)	36.4(42.7)	46.9(45.9)
	Neut	5.75(7.32)	5.93(6.15)	8.82(10.1)	9.49(7.76)	15.1(19.0)	12.0(9.73)
	Flx	6.56(8.61)	6.73(8.46)	12.3(19.2)	9.53(9.58)	17.9(22.5)	14.2(14.8)
OH ht.	Ext	25.4(29.1)	38.4(41.0)	30.3(33.6)	55.9(52.3)	38.9(45.4)	63.4(54.1)
	Neut	6.39(8.12)	8.77(7.83)	11.7(15.1)	14.6(12.0)	17.2(18.6)	22.4(14.1)
	Flx	7.44(9.30)	9.32(11.3)	11.4(14.2)	13.3(13.7)	20.8(26.5)	20.4(17.5)
Shoulder ht. pull	Neut	4.89(4.63)	6.67(6.17)	5.50(5.42)	8.20(8.21)	7.40(9.77)	8.83(7.50)
Shoulder ht. push	Neut	4.66(4.96)	6.63(6.27)	5.46(5.67)	7.25(6.52)	5.14(5.42)	9.21(8.15)
Oh pull	Neut	4.11(3.07)	7.33(6.53)	5.07(4.44)	6.71(5.54)	5.60(4.90)	9.59(7.97)

For the upper trapezius muscle along C4 ($F=1.84$ $P=0.1856$) and C7 ($F=0.00$ $P=0.9508$) levels, gender had no significant effect on the muscle activities during forceful exertions (lifting, pushing, and pulling) at knuckle, elbow, shoulder, and overhead heights. The results of the statistical analysis (ANOVA tables and all-pairwise comparison) are presented in Appendix G.

7.6 Section 4 - Comparison between the Muscles

The activities of the sternocleidomastoid muscle were significantly lower than the upper trapezius muscle along the C4 and C7 levels while lifting 25%, 50%, and 75% weights at knuckle height (Figure 41, Table 26). At elbow height, in the neutral neck posture, at 25% weight condition, the activities of the sternocleidomastoid muscle were lower than the upper trapezius muscle along the C4 and C7 levels. No difference was found in the activities of the upper trapezius muscle along the C4 and C7 levels. At 50% and 75% weight conditions, the upper trapezius muscle along C7 levels worked hardest, followed by the upper trapezius muscle along the C4 level and the sternocleidomastoid muscle. At shoulder and overhead heights, the activities of the upper trapezius muscle along C7 level was higher than the activities of the upper trapezius muscle along C4 level and the sternocleidomastoid muscle at neutral neck posture at 25%, 50%, and 75% weight conditions. The activities of the upper trapezius muscle along the C4 level were significantly higher than the sternocleidomastoid muscle.

At extended neck posture, while lifting 25%, 50%, and 75% weight at elbow height, the sternocleidomastoid muscle worked as hard as the upper trapezius muscle along the C4 and C7 levels (Figure 42, Figure 43, Table 27, Table 28). At shoulder height, for 25% weight condition, the sternocleidomastoid muscle worked as hard as the upper trapezius muscle along the C7 level. At 50% and 75% weight conditions, the sternocleidomastoid muscle worked as hard as the upper trapezius muscle along the C4 level. The activities of the upper trapezius muscle along the C7 level were higher than the upper trapezius muscle along C4 level and the sternocleidomastoid muscle. At overhead height, the sternocleidomastoid muscle worked as hard as the upper trapezius muscle along the C7 level at 25%, 50%, and 75% weight conditions.

At flexed neck posture, in general, the upper trapezius muscle along the C7 level worked hardest, followed by the upper trapezius muscle along the C4 level and sternocleidomastoid muscle (Figure 42, Figure 43, Table 27, Table 28). At elbow height, at 25% weigh condition, the activities of the upper trapezius muscle along C7 and C4

Table 26: N-EMG values for the sternocleidomastoid muscle and upper trapezius muscle along C4 and C7 during lifting at knuckle height and at elbow height in neutral, flexed, and extended posture at 25%, 50%, and 75% weight conditions. The values marked with the different letters (a, b, and c) are statistically significant.

	Lifting at knuckle height		
Weight	25%	50%	75%
Neck posture	Neut	Neut	Neut
SCM	4.24 (a) (±4.08)	4.55 (a) (±4.34)	5.44 (a) (±5.11)
TRPL	9.15 (b) (±4.10)	10.1 (b)(±4.48)	13.4 (b) (±6.98)
TRPU	7.62 (b) (±4.85)	11.1 (b)(±6.40)	15.5 (b) (±9.10)

	Lifting at elbow height								
Weight	25%	25%	25%	50%	50%	50%	75%	75%	75%
Neck posture	Ext	Neut	Flx	Ext	Neut	Flx	Ext	Neut	Flx
SCM	13.4 (a) (±16.7)	3.14 (a) (±2.65)	3.46 (a) (±3.34)	17.5 (a) (±20.2)	4.18 (a)(±3.17)	4.02 (a) (±2.88)	22.1 (a) (±20.9)	6.15 (a) (±7.31)	5.88 (a) (±5.07)
TRPL	9.52 (a) (±4.14)	10.8 (b) (±5.58)	14.4 (b) (±6.17)	14.8 (a) (±5.51)	15.8 (b) (±6.04)	18.8 (b) (±9.01)	20.8 (a) (±7.40)	21.1 (b) (±8.02)	26.4 (b) (±9.94)
TRPU	10.4 (a) (±6.40)	11.4 (b) (±7.21)	15.7 (b) (±9.67)	18.2 (a) (±10.8)	19.4 (c)(±9.90)	23.0 (c) (±12.4)	24.6 (a) (±13.8)	25.4 (c) (±15.2)	32.7 (c) (±15.5)

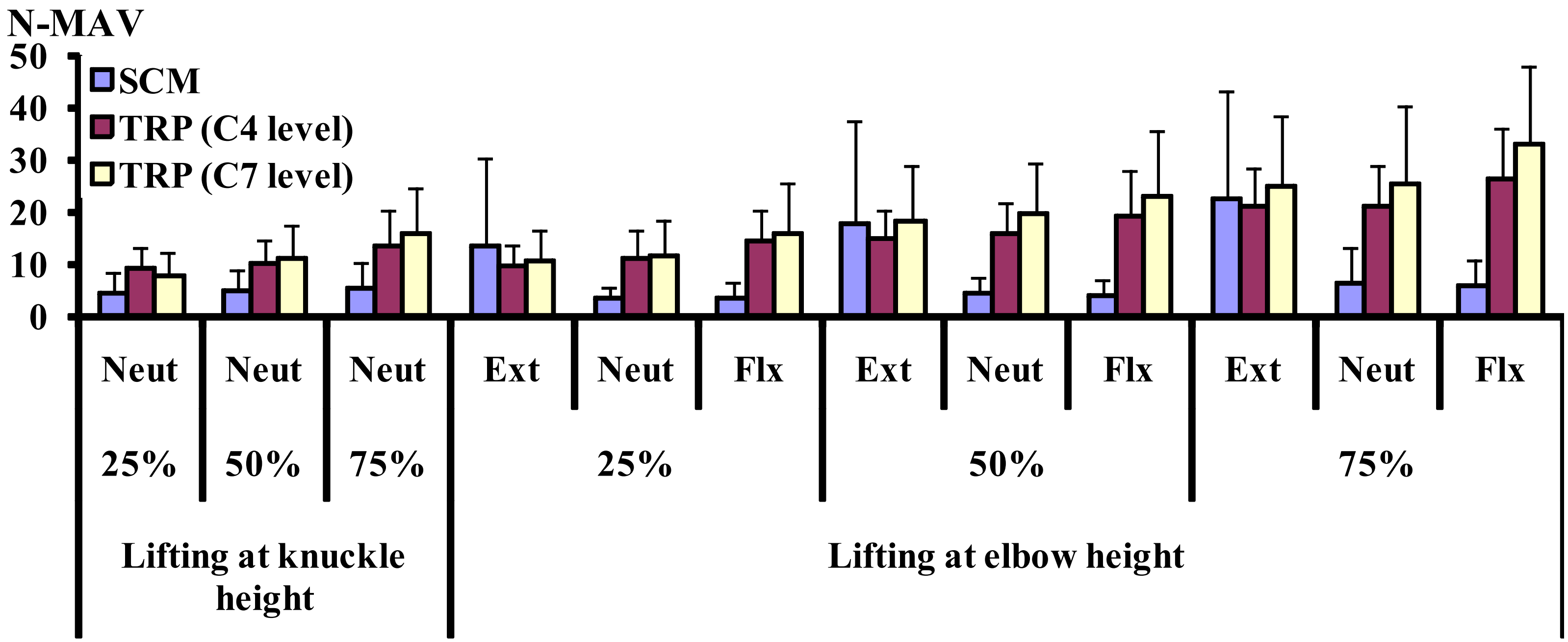


Figure 41: Muscle activity pattern for the sternocleidomastoid (SCM), and upper trapezius (TRP) muscle along C4 and C7 levels during lifting at knuckle height and at elbow height in neutral, flexed and extended posture at 25%, 50%, and 75% weight conditions.

Table 27: N-EMG values for the sternocleidomastoid, and upper trapezius muscle along C4 and C7 levels during lifting at shoulder height in neutral, flexed and extended posture at 25%, 50%, and 75% weight conditions. The values marked with the different letters (a, b, and c) are statistically significant.

	Lifting at shoulder height								
Weight	25%	50%	75%	25%	50%	75%	25%	50%	75%
Neck posture	Ext	Neut	Flx	Ext	Neut	Flx	Ext	Neut	Flx
SCM	20.3 (a)(14.9)	4.20 (a) (3.04)	4.64 (a) (4.00)	24.2 (a) (19.9)	6.88 (a) (4.84)	7.16 (a) (5.19)	30.8 (a) (24.7)	9.81 (a) (6.37)	11.0 (a) (8.12)
TRPL	16.4 (b) (8.48)	17.9 (b) (7.56)	23.7 (b) (12.6)	23.7 (a) (14.3)	27.5 (b) (14.1)	35.5 (b) (18.4)	32.7 (a) (18.8)	35.9 (b) (21.1)	50.7 (b) (30.7)
TRPU	23.5 (a) (15.2)	24.4 (c) (13.1)	29.4 (c) (18.5)	32.8 (b) (21.4)	36.2 (c) (22.3)	43.2 (c) (24.3)	44.7 (b) (30.5)	44.0 (c) (26.4)	57.6 (b) (36.2)

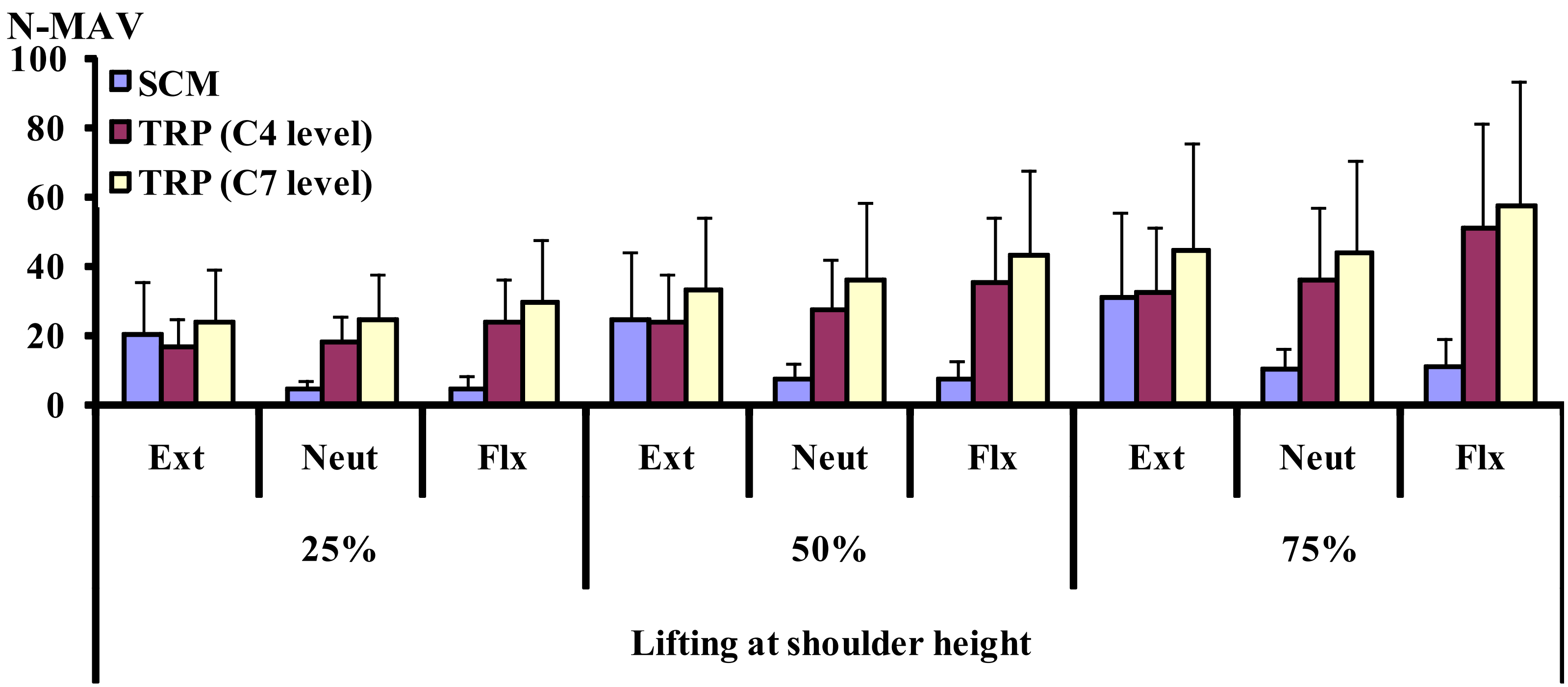


Figure 42: Muscle activity pattern for the sternocleidomastoid (SCM), and upper trapezius (TRP) muscle along C4 and C7 levels during lifting at shoulder in neutral, flexed and extended posture at 25%, 50%, and 75% weight conditions.

Table 28: N-EMG values for the sternocleidomastoid, and upper trapezius muscle along C4 and C7 levels during lifting at overhead height in neutral, flexed and extended posture at 25%, 50%, and 75% weight conditions. The values marked with the different letters (a, b, and c) are statistically significant.

	Lifting at overhead height								
Weight	25%	50%	75%	25%	50%	75%	25%	50%	75%
Neck posture	Ext	Neut	Flx	Ext	Neut	Flx	Ext	Neut	Flx
SCM	24.9 (a) (20.9)	5.96 (a) (4.78)	6.38 (a) (5.97)	34.2 (a) (26.7)	10.3 (a) (7.97)	9.68 (a) (8.39)	40.4 (a) (28.1)	16.6 (a) (11.5)	16.1 (a) (13.1)
TRPL	19.0 (b) (11.4)	17.8 (b) (8.07)	22.9 (b) (10.8)	26.9 (b) (12.1)	29.0 (b) (18.9)	34.8 (b) (18.8)	40.1 (a) (27.7)	42.4 (b) (21.7)	53.6 (b) (34.5)
TRPU	25.6 (a) (15.9)	25.0 (c) (15.0)	32.1 (c) (16.7)	36.1 (a) (19.9)	36.4 (c) (17.8)	46.3 (c) (24.3)	48.8 (a) (21.1)	50.9 (c) (22.0)	60.7 (b) (31.4)

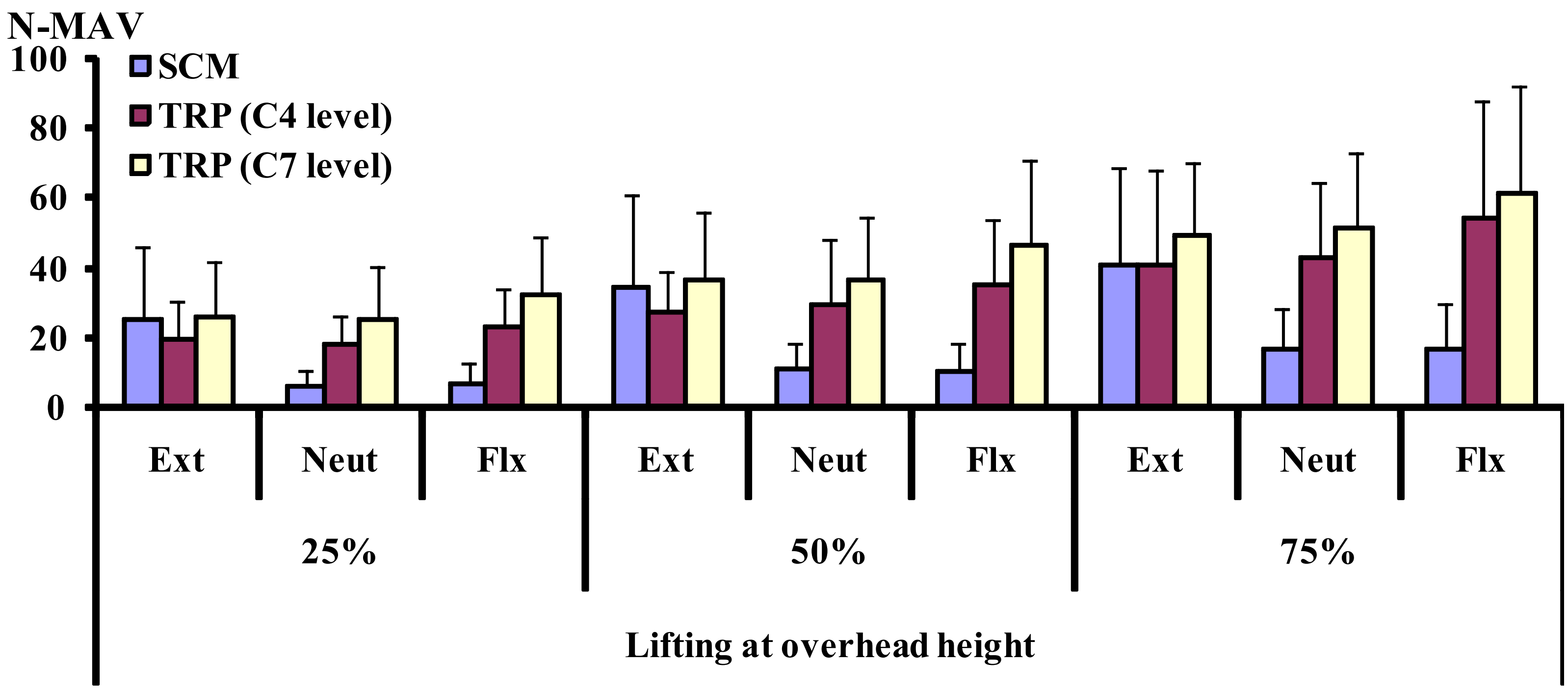


Figure 43: Muscle activity pattern for the sternocleidomastoid (SCM), and upper trapezius (TRP) muscle along C4 and C7 levels during lifting at overhead height in neutral, flexed and extended posture at 25%, 50%, and 75% weight conditions.

Table 29: N-EMG values for the sternocleidomastoid, and upper trapezius muscle along C4 and C7 levels during pushing and pulling at shoulder height and overhead at 25%, 50%, and 75% weight conditions. The values marked with the different letters (a, b, and c) are statistically significant.

	Pulling at shoulder height			Pushing at shoulder height			Pulling at overhead height		
Weight	25%	50%	75%	25%	50%	75%	25%	50%	75%
Neck posture	Neut	Neut	Neut	Neut	Neut	Neut	Neut	Neut	Neut
SCM	5.78 (a)(5.44)	6.85 (a) (6.97)	8.12 (a) (8.59)	5.64 (a) (5.64)	6.35 (a) (6.07)	7.17 (a) (7.11)	5.72 (a) (5.28)	5.89 (a) (5.00)	7.60 (a) (6.81)
TRPL	8.25 (b) (4.50)	8.55 (a) (4.33)	9.99 (a) (5.49)	7.19 (a) (4.36)	7.22 (a) (4.18)	8.27 (a) (4.35)	6.88 (a) (3.72)	7.17 (a) (4.02)	7.43 (a) (4.22)
TRPU	8.14 (b) (6.37)	8.52 (a) (7.74)	10.4 (a) (7.42)	3.29 (b) (2.26)	3.37 (b) (2.75)	3.82 (b) (2.97)	2.51 (b) (2.09)	2.61 (b) (2.75)	3.57 (b) (4.19)

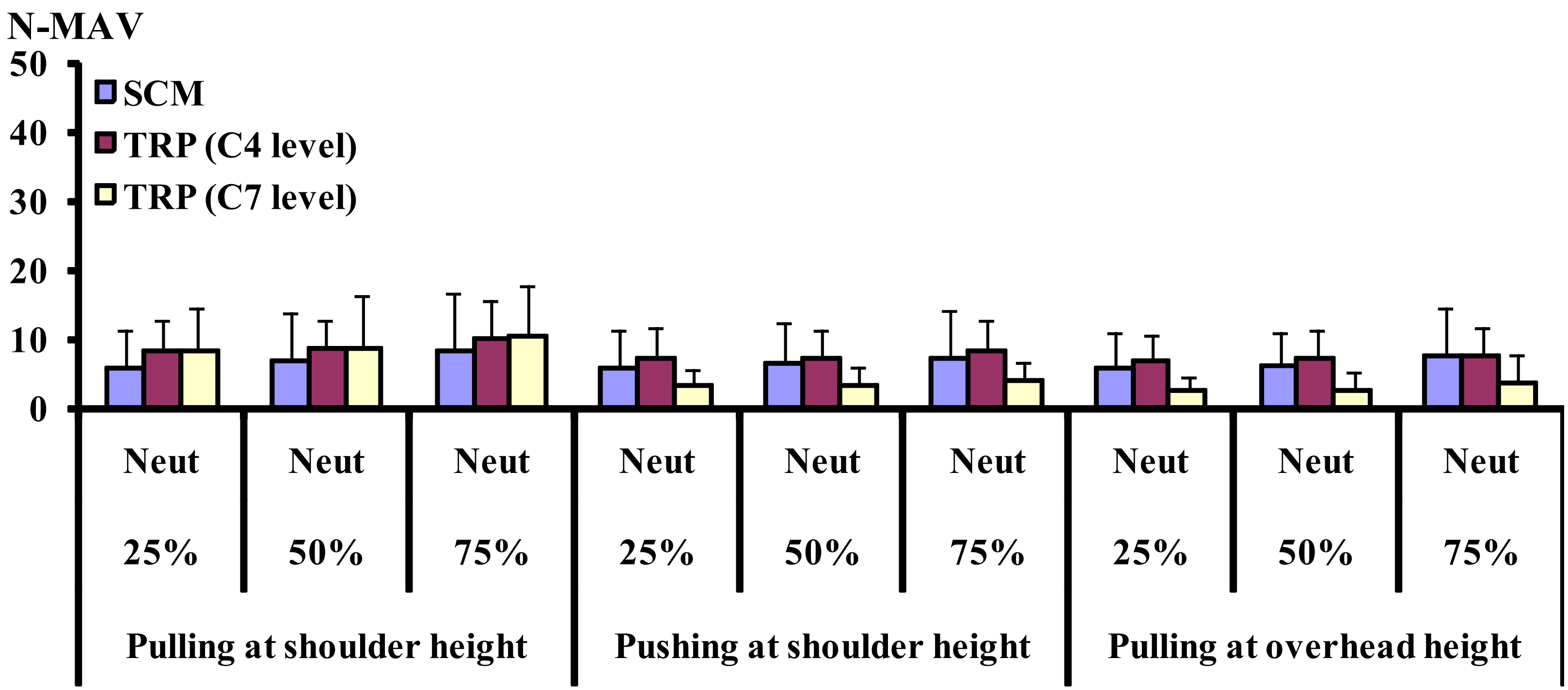


Figure 44: Muscle activity pattern for the sternocleidomastoid (SCM), and upper trapezius (TRP) muscle along C4 and C7 levels during pushing and pulling at shoulder height and overhead at 25%, 50%, and 75% weight conditions

levels were higher than the sternocleidomastoid muscle, and no difference was found between the activities of the upper trapezius muscle along C7 and C4 levels. At elbow height during 50% and 75% weight conditions, as well as and shoulder and overhead heights during 25% and 50% weight conditions, the upper trapezius muscle along C7 level worked hardest followed by the upper trapezius muscle along the C4 level and sternocleidomastoid muscle. At shoulder and overhead heights, during 75% weight conditions, the activities of the upper trapezius muscle along C7 and C4 levels were higher than the sternocleidomastoid muscle, but no difference was found between the activities of the upper trapezius muscle along C7 and C4 levels.

During pulling at shoulder height, no difference was found in the activities of the sternocleidomastoid muscle and the upper trapezius muscle along C7 and C4 levels at 50% and 75% weight conditions (Figure 44, Table 29). At 25% weight condition, the upper trapezius muscle along C7 and C4 levels worked harder than sternocleidomastoid muscle. During pulling at shoulder and overhead heights, the activities of both the sternocleidomastoid and the upper trapezius muscles along the C4 level were significantly higher than the upper trapezius muscle along C4 level.

7.7 Section 5 - Biomechanical Modeling

The internal forces exerted by the sternocleidomastoid (P<0.001), levator scapula (P<0.001), semispinalis capitis (P<0.001), and upper trapezius (P<0.001) muscles increased with the increase in the weight lifted at the elbow height. Unilateral forces exerted by the sternocleidomastoid muscle increased from 12.0 (±3.2) to 21.2(±6.2) to 30.4(±9.2) N with an increase in the weight from 25% to 50% to 75% (Figure 45). The corresponding values for the levator scapula and semispinalis capitis muscle increased from 8.8(±2.3) to 15.5(±4.6) to 22.3(±6.8) and 9.6(±2.6) to 16.9(±5.0) to 24.3(±7.4), respectively. For the upper trapezius muscle, the internal forces values increased from 6.0(±1.6) to 10.6(±3.1) to 15.2(±4.6).

The correlation coefficients between the EMG and the force data for the sternocleidomastoid and the upper trapezius muscle (along C4 level) were 0.8968 and 0.8896, respectively. The results of the biomechanical modeling are presented in Appendix H.

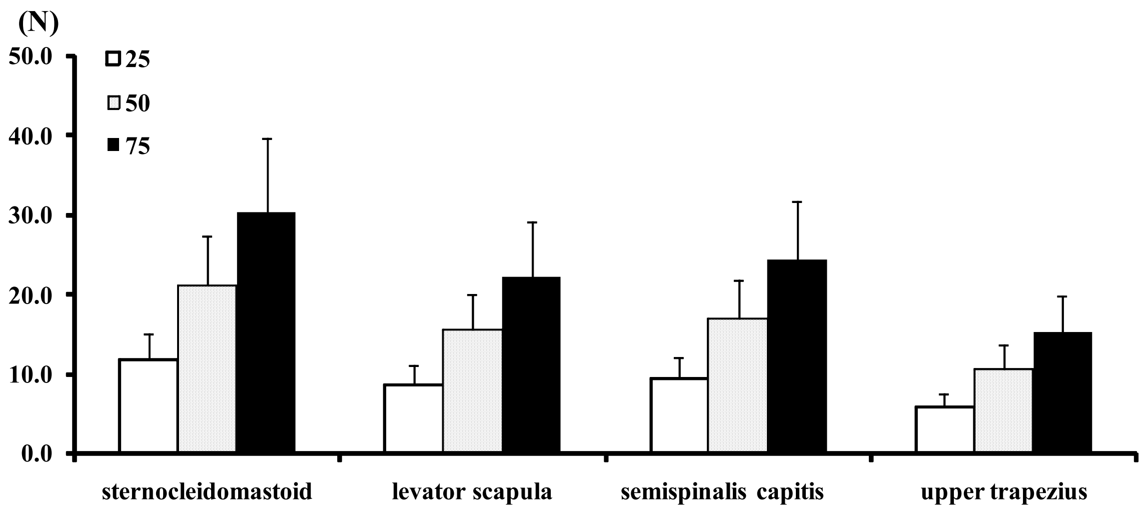


Figure 45: Forces exerted by the sternocleidomastoid, levator scapula, semispinalis capitis, and upper trapezius muscles at C4-C5 level during isometric lifting task at elbow height in neutral neck posture

CHAPTER 8: DISCUSSION AND CONCLUSION

In this study, the manual material handling activities common at various workplaces were studied by simulating isometric lifting, pushing, and pulling tasks at various heights in different neck postures. The physical risk factors associated with neck disorders during these forceful arm exertions were evaluated by studying the activities of major anterior and posterior neck muscles, using electromyography. Additionally, a biomechanical model of the neck was developed to quantify the internal forces exerted by the neck muscles at C4-C5 level.

8.1 EMG Study

The results of the EMG study supported our research hypotheses. In the following paragraphs, the results of the experimental study and the corresponding research hypothesis are discussed.

8.1.1 General Hypothesis 1

Neck muscles, sternocleidomastoid and upper trapezius (C4 and C7 levels), were active during all the forceful arm exertions and thus, data supported our general hypothesis 1. A consistent muscle activity pattern was observed for all the participants. The lowest level of activation (between 3 to 4 %) for the sternocleidomastoid muscle was observed during lifting 25% weights at knuckle and elbow heights. The sternocleidomastoid muscle worked hardest (40.0%) during lifting 75% weight at overhead heights in an extended neck posture. For the upper trapezius muscle along the C4 level, the muscle worked between 9 to 10 %, during lifting at 25% weight at knuckle and elbow heights. The lowest activation of 6.9 % was observed during overhead pulling at 25% weight condition. The muscle worked hardest (53.0%) during lifting 75% weight condition at overhead height in a flexed neck posture. For the upper trapezius muscle along the C7 level, the lowest activation of 2.5% of MVC was observed during overhead pulling at 25% weight condition. The muscle worked 7.6% and 11.5% during lifting 25% weight at knuckle and elbow height, respectively. The highest activation, 60.8 % of MVC, for the upper trapezius muscle along the C7 level, was observed at overhead height, lifting 75% weight in flexed neck posture.

8.1.2 General Hypothesis 2

The activities of the neck muscles increased, corresponding to the increase in the lifting weight or forces exerted (Nimbarte, 2008; Nimbarte et al., 2008), and thus supported our general hypothesis 2. The activities of the sternocleidomastoid muscle increased by 7.0%, 33.4%, 63.9%, and 73.3%, with an increase in the weight from 25% to 50%, while performing lifting in neutral neck posture at knuckle, elbow, shoulder, and overhead heights, respectively (Figure 46 a). The corresponding increase in the muscle activities with an increase in the weight from 50% to 75% was 20.8%, 47.0%, 42.5%, 60.8%, respectively. The activities of the upper trapezius muscle along C4 level increased by 11.4%, 46.0%, 53.8%, and 63.0%, with an increase in the weight from 25% to 50%, and by 32.1%, 33.0%, 30.6%, and 46.0% with an increase in the weight from 50% to 75% while performing lifting in neutral neck posture at knuckle, elbow, shoulder, and overhead heights, respectively (Figure 46 b). The corresponding values for the upper trapezius muscle along C7 level increased by 46.1%, 69.3%, 48.4%, and 45.3% with an increase in the weight from 25% to 50%, and by 40.0%, 30.6%, 21.5%, and 40.0% with an increase in the weight from 50% to 75% (Figure 46 c).

This observed increase in the activation of the upper trapezius muscle along the C7 level, with an increase in the weight, is consistent with previous investigations. Astrom et al. (2007) reported almost a linear relationship between the weight lifted at knuckle height and the activities of upper trapezius muscle along C7 level. Farina et al. (2002) reported an increase in the activities of the upper trapezius muscle along the C7 level with an increase in the weight from 0 kg to 0.5kg to 1 kg, lifted at the shoulder height (90º of arm abduction). Anton et al. (2005) also observed increased upper trapezius activity with an increase in the load applied to the hand.

8.1.3 Task Specific Hypothesis 1

Independent of the weight lifted and the lifting heights, the anterior neck muscle (sternocleidomastoid) showed higher EMG activities at an extended neck position, compared to the neutral and flexed neck positions, and the posterior neck muscle (upper trapezius) showed higher EMG activities at the flexed neck position, compared to the neutral and extended neck positions (Nimbarte, 2008; Nimbarte et al., 2008; Nimbarte et al., 2009). This observed trend in the neck posture and muscle activity supported our task specific hypothesis 1.

On an average, change in the neck posture from neutral to extension and from flexion to extension increased the activities of the sternocleidomastoid muscle by 327.8%

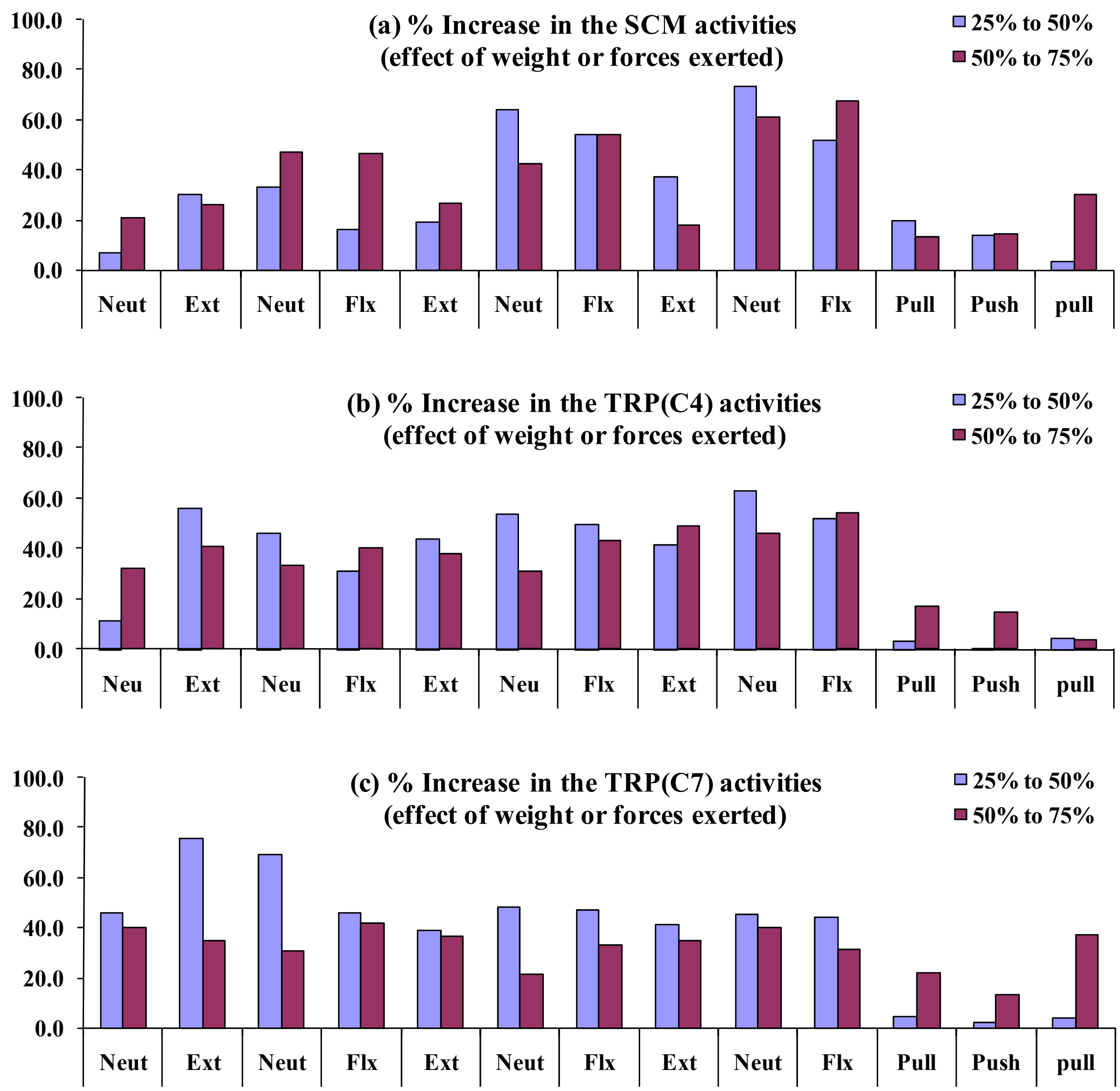


Figure 46: Percent increase in the activities of (a) sternocleidomastoid, (b) upper trapezius (along C4), and (c) upper trapezius (along C7) muscles with the increase in the weight lifted from 25% to 50% and from 50% to 75%.

Table 30: Percent increase in the activities of the neck muscles with the change in the neck posture.

Task	Weight	Sternocleidomastoid		Upper trapezius (C4 level)		Upper trapezius (C7 level)	
		Neutral to Extension	**Flexion to Extension**	**Neutral to Flexion**	**Extension to Flexion**	**Neutral to Flexion**	**Extension to Flexion**
Lifting at elbow ht.	25%	328.2	288.5	32.6	51.2	37.5	51.5
	50%	318.3	335.4	18.8	26.8	18.6	26.1
	75%	259.8	276.3	25.1	26.4	28.9	33.0
Lifting at shoulder ht.	25%	567.7	338.1	32.6	44.2	20.4	24.7
	50%	401.5	239.1	29.0	49.9	19.3	31.8
	75%	383.7	179.2	41.1	55.2	30.9	28.7
Lifting at overhead ht.	25%	317.5	290.0	28.7	20.2	28.3	25.5
	50%	231.2	253.5	20.1	29.3	27.2	28.1
	75%	143.3	149.8	26.5	33.8	19.2	24.4
Average		**327.9**	**261.1**	**28.3**	**37.4**	**25.6**	**30.4**

and 261.0%, respectively (Table 30). The activities of the upper trapezius muscle along the C4 increased by 28.3% and 37.4% with the change in the neck posture from neutral to flexion and from extension to flexion, respectively. The corresponding values for the upper trapezius muscle along the C7 increased by 25.6% and 30.4%.

Consistent with our findings, increased activation of the upper trapezius muscle along the C7 level, at the flexed neck posture was reported in a number of studies evaluating sitting work postures (Harms-Ringdahl et al., 1986; Schüldt et al., 1986; Villanueva et al., 1997). Moreover the observed neck-posture and muscle-activation trend is in agreement with the muscle force-length relationship, i.e., lower activation at shorter length and higher values at increased length (Chaffin et al., 1984).

8.1.4 Task Specific Hypothesis 2

The activities of the neck muscles were found to increase with the increase in the lifting heights from knuckle to elbow to shoulder to overhead (Nimbarte et al., 2009), supporting our task specific hypothesis 2. The activities of the upper trapezius muscle along the C7 level were found to be most sensitive to the change in the lifting height. The muscle activities increased by 62.8%, 90.0%, and 7.6%, with the increase in the lifting height from knuckle to elbow, elbow to shoulder, and from shoulder to overhead, respectively (Table 31). For the upper trapezius muscle along the C4 level, the muscle activities increased by 43.7%, 71.6%, with the increase in the lifting height from knuckle to elbow, elbow to shoulder. The muscle activities of the upper trapezius muscle along the C4 level did not show a consistent trend for the increase in the lifting heights from shoulder to overhead heights. For the sternocleidomastoid muscle, the muscle activities increased by 54.1% and 41.7%, with the increase in the lifting height from elbow to shoulder and shoulder to overhead, respectively. No consistent trend was observed for the sternocleidomastoid muscle activities with an increase in the lifting heights from knuckle to elbow.

The observed trend in the activities of the upper trapezius muscle along the C7 with the change in the lifting height is in agreement with the results of the previous investigations. Anton et al. (2005) studied 21 masons while performing bricklaying tasks at different work heights. Greater upper trapezius muscle (along the C7 level) activity was found while working at and above shoulder height, compared to the lower heights. A similar effect of the height was found among sheet metal workers performing curved cuts in sheet metal using three different designs of aviation snips at waist and shoulder height (Anton et al., 2005). Ortengren et al. (1991) also reported greater upper trapezius muscle activity when using a powered screwdriver at 'eye' level, compared to 'hip' level.

Table 31: Percent increase in the activities of the neck muscles with the increase in the lifting heights.

Weight	25%			50%			75%			**Average**
Neck Posture	Ext	Neut	Flx	Ext	Neut	Flx	Ext	Neut	Flx	
	Sternocleidomastoid									
knuckle to elbow		-19.3			0.6			22.4		**1.2**
elbow to shoulder	51.4	33.8	34.3	38.7	64.5	78.1	39.3	59.5	87.7	**54.1**
shoulder to overhead	22.3	42.0	37.4	40.9	50.1	35.2	31.2	69.4	46.7	**41.7**
	Upper trapezius (C4 level)									
knuckle to elbow		18.7			55.6			56.7		**43.7**
elbow to shoulder	72.9	64.9	64.9	59.6	73.7	88.6	56.6	70.5	92.3	**71.6**
shoulder to overhead	15.9	-0.5	-3.4	13.8	5.4	-1.8	22.7	17.9	5.7	**8.4**
	Upper trapezius (C7 level)									
knuckle to elbow		50.7			74.7			62.9		**62.8**
elbow to shoulder	126.2	112.7	86.3	79.5	86.5	87.6	82.0	73.4	76.1	**90.0**
shoulder to overhead	8.7	2.6	9.3	10.2	0.4	7.1	9.1	15.8	5.5	**7.6**

8.2.5 Task Specific Hypothesis 3

The activities of the upper trapezius muscle along the C4 and C7 levels showed higher sensitivity to the change in direction of force exertion than the sternocleidomastoid muscle. During lifting at shoulder height, the upper trapezius muscle along the C4 level worked 116.9%, 222.2%, and 260.1% more than pulling activity at 25%, 50%, and 75% weight conditions, respectively (Table 32). At an overhead height, the muscle worked 159.0%, 305.1%, and 470.8% more during lifting than during pulling at 25%, 50%, and 75% weight conditions. The corresponding values for the upper trapezius muscle along the C7 level at shoulder and overhead heights were 199.9%, 325.6%, and 322.7% and 896.7%, 1294.9%, and 1324.9%, respectively. For the sternocleidomastoid muscle, the activities during lifting at shoulder were 13.7%, 43.2% higher than during pulling at 50% and 75% weight conditions. The muscle activities during lifting at overhead height were 15.8%, 94.2%, and 139.8% higher than during pulling at 25%, 50%, and 75% weight conditions.

8.2.6 Task Specific Hypothesis 4

The activities of the neck muscles during isometric pulling tasks at shoulder height were higher than the isometric pushing tasks, supporting our task specific hypothesis 4. The upper trapezius muscle along the C7 level was found to be the most sensitive to the change in the direction of force application, followed by the upper trapezius muscle along the C4 level. The activities of the upper trapezius muscle along the C4 level were 14.7%, 18.3%, and 20.8% higher during pulling than during pushing.

The activities of the upper trapezius muscle along the C7 level during pulling were 147.1%, 152.3%, and 172.2%, higher than during pushing. The corresponding values for the sternocleidomastoid muscle were 2.7%, 8.0%, and 6.7%, respectively.

Table 32: Percent increase in the activities of the neck muscles with the change in the direction of force application (lifting, pushing, and pulling)

	Shoulder height			Overhead height		
Weight	25%	50%	75%	25%	50%	75%
Sternocleidomastoid						
lifting-pulling	-16.9	13.7	43.2	15.8	94.2	139.8
lifting-pushing	-14.7	22.7	52.9			
pulling-pushing	2.7	8.0	6.7			
Upper trapezius (C4 level)						
	25	50	75	25	50	75
lifting-pulling	116.9	222.2	260.1	159.0	305.1	470.8
lifting-pushing	148.9	281.2	334.8			
pulling-pushing	14.7	18.3	20.8			
Upper trapezius (C7 level)						
lifting-pulling	199.9	325.6	322.7	896.7	1294.9	1324.9
lifting-pushing	641.2	973.6	1050.6			
pulling-pushing	147.1	152.3	172.2			

8.3 Biomechanical Model of the Neck

The compressive forces exerted by the four neck muscles at the C4-C5 level during the isometric lifting task at elbow height were 72.6 (19.4), 128.5(37.7), and 184.4(56.1) N corresponding to the 25%, 50%, and 75% weight conditions (Nimbarte et al., 2009). Among the four muscles, the sternocleidomastoid muscle exerted highest forces unilaterally (12.0 (3.2), 21.2(6.2), 30.4(9.2) N at 25% to 50% to 75% weight conditions), followed by the semispinalis capitis (9.6(2.6), 16.9(5.0), 24.3(7.4) at 25% to

50% to 75% weight condition) and levator scapula (8.8(2.3), 15.5(4.6), 22.3(6.8) at 25% to 50% to 75% weight condition) muscles. The upper trapezius muscle exerted the lowest forces (6.0(1.6), 10.6(3.1), 15.2(4.6) at 25% to 50% to 75% weight condition).

The forces exerted by the sternocleidomastoid and upper trapezius muscles showed a high correlation with the EMG data. Based on the EMG study and for similar exertions, N-MAV (% MVC) values for sternocleidomastoid and upper trapezius muscles were 3.4% to 4.2% to 6.2% and 10.9% to 15.9% to 21.1%, respectively. If the force data is extrapolated using the maximum EMG data, then the maximum force exerted by the sternocleidomastoid and upper trapezius muscles will be approximately 442 and 65 N, respectively. The maximum forces for sternocleidomastoid and upper trapezius muscles, as reported by Choi and Vanderby (1999) using a biomechanical model of the neck, were 304 and 76 N, respectively, which are similar to the findings of this study.

8.4 Anterior versus Posterior Neck Muscles

The upper trapezius muscle, especially along the C7 level, has been widely studied in occupational investigations to evaluate neck and upper extremity disorders. To our knowledge, no previous study evaluating occupational tasks or forceful arm exertions has reported the activities of the sternocleidomastoid muscle and the upper trapezius muscle in the cervical region. While evaluating neck disorders, understanding the activation of these muscles is vital, as they are bigger (surface) muscles in the neck region and anatomically couple the shoulder to the skull. Such an anatomical orientation may require these muscles to support the shoulder during forceful arm exertions. In confirmation with our claim, the results of this study clearly show that, similar to the upper trapezius muscle along the C7, the activation of the sternocleidomastoid muscle and the upper trapezius muscle in the cervical region was sensitive to the lifting weight, neck posture, lifting heights, and direction of force exertions.

During the lifting tasks performed at a neutral neck posture at various heights, on an average the upper trapezius muscle along the C4 level worked 215.5% harder than the sternocleidomastoid muscle (Table 33). The sternocleidomastoid muscle worked 15.9% harder than the upper trapezius muscle along the C4 level during the lifting tasks performed at an extended neck posture. During the lifting tasks performed at a flexed neck posture, the upper trapezius muscle along the C4 level worked 327.9% harder than the sternocleidomastoid muscle.

The activation of the upper trapezius muscle along the C7 level was 19.5%, 22.3%, and 28.7% more than the activation of the upper trapezius muscle along the C4 level during lifting tasks performed at various heights in neutral, extended, and flexed neck postures. Johnson and Pandyan (2005) also reported similar trends during isometric shoulder shrugging and abduction. The uneven activation of the trapezius muscle could be mainly due to the variation in the cross sectional areas of these fibers and the uneven spectral distribution of type I versus type II fibers. Lindman et al. (1990) found an unsystematic relationship between the cross-sectional area and the fiber type in the cervical part of the upper trapezius muscle. Further supporting this observation, Holtermann et al. (2005) recently found an unsystematic relationship between the force

Table 33: Percent difference in the activities of neck muscles

Lifting in neutral neck posture			
		TRP(C4) -SCM	TRP(C7) -TRP(C4)
knuckle height	25%	115.4	-16.7
	50%	123.8	9.2
	75%	147.0	15.8
Elbow height	25%	246.0	5.7
	50%	278.8	22.6
	75%	242.9	20.4
Shoulder height	25%	326.4	36.4
	50%	300.1	31.6
	75%	266.6	22.4
Overhead height	25%	198.8	40.6
	50%	181.1	25.4
	75%	155.1	20.2
Average		**215.2**	**19.5**
Lifting in flexed neck posture			
		TRP(C4) -SCM	TRP(C7) -TRP(C4)
Elbow height	25%	316.2	9.7
	50%	368.5	22.3
	75%	348.7	24.0
Shoulder height	25%	411.1	23.9
	50%	396.2	21.6
	75%	359.7	13.5
Overhead height	25%	259.3	40.2
	50%	260.4	32.7
	75%	231.4	13.2
Average		**327.9**	**22.3**

Lifting in extended neck posture			
		SCM-TRP(C4)	TRP(C7) -TRP(C4)
Elbow height	25%	41.1	9.4
	50%	17.8	23.0
	75%	6.0	17.8
Shoulder height	25%	23.5	43.1
	50%	2.4	38.3
	75%	-5.7	37.0
Overhead height	25%	30.5	34.3
	50%	26.8	34.0
	75%	0.8	21.8
Average		**15.9**	**28.7**
Pushing and pulling in neutral neck posture			
		TRP(C4)-SCM	TRP(C4) -TRP(C7)
Pulling at shoulder height	25%	42.8	1.4
	50%	23.0	0.4
	75%	23.0	-4.1
Pushing at shoulder height	25%	27.4	118.4
	50%	13.7	114.0
	75%	15.3	116.2
Pulling at overhead height	25%	20.2	173.7
	50%	21.7	174.7
	75%	-2.2	107.6
Average		**20.7**	**89.1**

generation and the average muscle fiber conduction velocity in the region of upper trapezius superior to C7.

During the pushing and pulling tasks, on an average the upper trapezius muscle along the C4 level worked 20.7 %, and 89.1% harder than the sternocleidomastoid and upper trapezius muscles, respectively.

8.5 Benefits of the Study – Understanding Probable Risk Factors

Epidemiologically, manual material handling activities requiring forceful arm exertions have been associated with neck disorders. In general, determination of the biomechanical or physiological pathways of the MSD requires an understanding of the load-response relationship. In the National Research Council's (1999) conceptual model about the physiological pathways of MSD, knowledge about the load-response relationship has been identified as one of the very basic, yet crucial, components. Such understanding is linked with learning the adaptation strategies of the musculoskeletal system and the analysis of impairment and disability pathways. The results of this study indicate that the neck muscles play an active role during isometric lifting, pushing, and pulling tasks at various heights in different neck postures, conforming a positive load-response relationship.

Workers during a variety of occupational tasks perform exertions repetitively, further elevating the loads generated on the neck muscles. In case of repetitive exertions, the activities requiring muscle exertion of more than 20% of the MVC are considered to be probable risk factors, associated with the development of MSD (Hagberg, 1984;

Larsson et al., 1990). Among the various exertions examined in this study, some of the probable physical exertions associated with the development of neck MSD could be:

1) lifting heavy weights (75%) at elbow height in neutral, flexed, and extended neck posture
2) lifting weights (25%, 50%, and 75%) at shoulder height in neutral, flexed, and extended neck posture
3) lifting weights (25%, 50%, and 75%) at overhead height in neutral, flexed, and extended neck posture

8.6 Cervical Spine Disorders - Possible Pathways

Overall, the results of this study indicate that the neck muscles play an active role during manual materials handling activities requiring forceful arm exertions. While translating the findings of this study into the physical risk factors associated with neck disorders, it is important to understand the possible MSD pathways. Armstrong et al. (1993) presented a conceptual model describing the pathways involved in the pathogenesis of cumulative neck and upper limb MSD. During work activities, the internal forces acting upon the musculoskeletal system require a response by the body. The response could be physiological or biomechanical in nature, e.g., increased circulation, local muscle fatigue (Hatipkarasulu et al., In review) etc. The cumulative work activities could require a continued or excessive response, which might further affect the body's ability to deal with further responses. In the scenarios of insufficient time (rest period) the reorganization or the regeneration process of the body tissue might be affected, reducing the available capacity for response. The repetition and/or accumulation of this phenomenon over the time may cause structural tissue deformation. Following are the some plausible responses by the human body and the resulting deformations:

1) Physical (especially heavy) exertion could rupture the muscle's z-discs, leading to the production of metabolites and other inflammatory chemicals activating the pain receptors through edema or other mechanisms. The re-orientation of collagen in the muscles could improve the condition over a period of time, however cumulative work requirements reinitiate the cycle further increasing the discharge of the metabolites and inflammatory chemicals causing muscle tension and pain (Hagberg, 1984).
2) The work activities requiring frequent contractions above 20% of the MVC and few rest breaks could decrease the local blood flow. Reduced blood flow could cause the myalgia (muscle pain) (Larsson et al., 1990).
3) The repeated loading could generate two types of force at the tendons, causing inflammation. The first is increased friction due to the uniaxial tensile forces generated or transmitted to the muscle. The second is the reaction forces acting transversally where the tendon passes over adjacent hard and soft structures such as bursae and retinaculae (Ashton-Miller, 1999; Radwin and Lavender, 1999). The friction between the tendon and its adjacent surfaces may cause the surface degeneration in tendons (Ashton-Miller, 1999).

4) The above muscle and tendon specific deformations mostly account for the mylgia or pain type of musculoskeletal disorders. The internal forces as proposed by Armstrong et al. (1993), in addition to causing muscle and tendon specific deformation, could also be transmitted to the other viable or vulnerable structures, in this case on the cervical spine. The neck muscles were found active during all the forceful arm exertions and exerted approximately 184.4 (56.1) N of forces during lifting heavy weights (75% of individual maximum strength) at elbow heights. The corresponding EMG activation for the sternocleidomastoid and upper trapezius muscles was 6.2% and 20%, respectively. These muscles worked as hard as 40% (sternocleidomastoid muscle during lifting 75% weight at overhead heights in extended neck posture) to 60% (upper trapezius muscle during lifting 75% weight at overhead heights in flexed neck posture). Thus the forces exerted by the neck muscles on the cervical spine during performing lifting at higher heights in extreme neck postures could be substantially higher. If we consider lifting in neutral neck posture, neck muscles work approximately 2 to 2.5 times more at shoulder and overhead heights compared to at elbow height, increasing the forces exerted on the cervical spine at C4-C5 level in the range of 365 to 461 N. These excessive compressive forces acting on the cervical spine could cause impingement of nerves and spinal cord passing through the cervical spine, causing cervical spine pathologies such as disc herniation or cervical myelopathy (Figure 47).

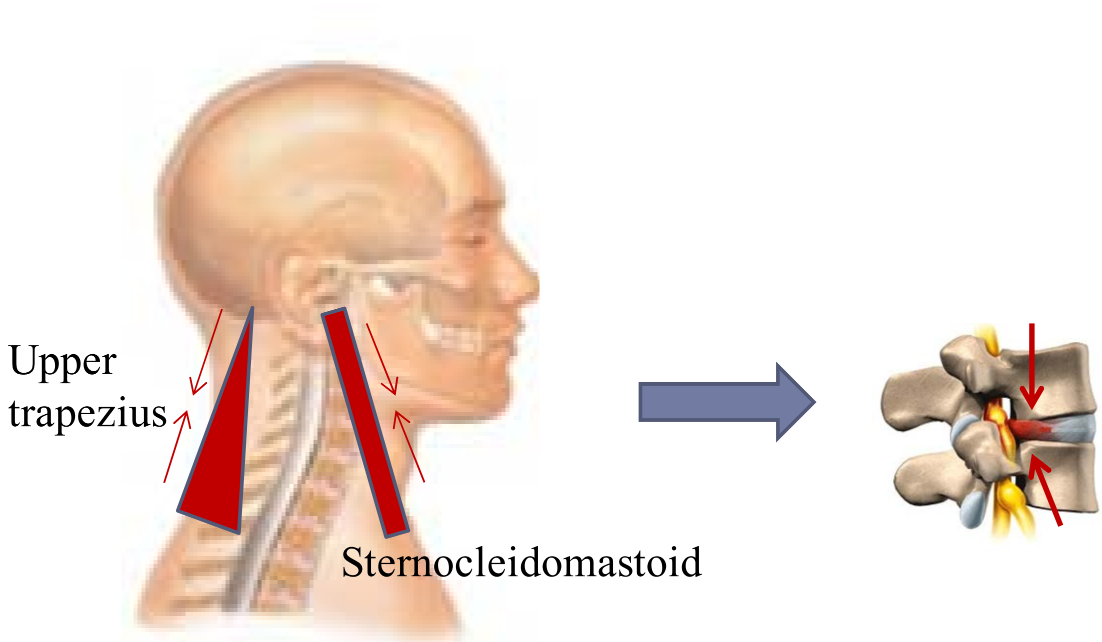


Figure 47: Cervical spine disorder- a possible pathway

8.7 Limitations of the Study

The laboratory based nature of this study imposes a few limitations. First, the tasks tested in this study rarely resemble the actual tasks performed at the workplaces. At actual workplaces workers are often involved in more complex static and mostly dynamic exertions. The primary purpose of this investigation was to get a basic idea about the role played by the neck muscles during forceful arm exertions therefore only simple isometric exertions were studied. Second, actual work sites are characterized by harsh outdoor environments due to noise, vibration, space, and time constraints. Such task specific factors could impose psychosocial stresses, further impacting muscle activation. Third, for standardization purposes, the participants lifted certain percentages of their maximum strength. In actual work conditions, workers lift weights of different sizes and dimensions regardless of body size or strength. Fourth, relatively younger people with less experience in physically demanding work were tested. The ability of the participants to lift or exert forces might have been less than that of industrial workers. Fifth, the EMG data was normalized with respect to muscle activation at maximum voluntary contraction. The ability to maximally activate all motor units depends on many factors, such as the muscle activated, training level, motivation, and most importantly posture (Soderberg and Knutson, 2000). People are not used to exerting high level forces using cervical muscles and wide range of motion of the cervical spine makes length-tension relationship for the neck muscle greatly dependent on the neck posture. The participants of this study did not undergo any training, they were not encouraged verbally during the force exertion, and while recording the maximum EMG for the sternocleidomastoid muscle the participants' neck postures were not precisely controlled. Due to these factors, it is possible that the EMG activations determined during the MVC exertions were slightly underestimated.

8.8 Possible Intervention

It is essential to conduct prospective ergonomic intervention studies targeting neck MSD among various occupational groups to understand a positive load-response relationship between the neck muscle activities and manual material handling tasks requiring forceful arm exertions. Some possible intervention strategies could be:

8.8.1 Avoiding Extreme Neck Postures

Neck muscles worked hardest (range of 40% to 60% of MVC) while performing heavy exertions at extreme neck postures (flexed and extended neck postures) at elbow, shoulder, and overhead heights. Alternative methods or equipment should be used to avoid heavy exertions at extreme neck postures. Example: Installation of large windows and sheet materials requires workers to lift and carry heavy and bulky objects in extreme neck postures. Instead, vacuum lifters could be used while installing or handling large windows and sheet materials (NIOSH, 2007).

8.8.2 Changing the Direction of Force Application

During the exertions performed at shoulder and overhead heights, neck muscles work less during pulling exertions compared to pushing (and lifting). Therefore, alternative equipment or strategies could be used to change the direction of force application to pulling (from lifting). For example, instead of lifting and moving sections of charged concrete hoses, skid plates also known as "hose placing discs" could be used (NIOSH, 2007) to change the direction of force application from lifting to pulling.

8.8.3 Using Lighter Materials

Neck muscles were active during all the forceful arm exertions and their activities increased with an increase in the weight lifted or forces exerted. Alternative materials or equipment must be used to avoid handling of heavy objects in the sagittal plane between elbow to overhead heights. For example, (1) regular masonry work involves lifting of concrete blocks at or above shoulder level. Standard-weight concrete blocks, measuring

$0.2 \times 0.2 \times 0.4$m, weigh approximately 16kg; instead, light-weight concrete blocks, approximately 10 pounds lighter, could be used (Anton et al., 2005); (2) Mixing of mortar requires lifting of heavy cement bags and also repetitive shoveling of sand into the mixer. Instead, big bags of pre-blended mortar and grout mix (including sand, pigments, and admixtures) weighing 907 – 1361kg could be used. Such bags could be moved by forklift or boom truck over a conventional mortar mixer and released into the silo by pulling a hitch pin on the bag (NIOSH, 2007).

8.9 Conclusions

1) Neck muscles play an active role during forceful arm exertions and heavy lifting tasks.
2) The highest activation of about 40% was observed for the sternocleidomastoid muscle during lifting 75% weight at overhead heights in an extended neck posture. The highest activation for the upper trapezius muscle, 53% along the C4 level, 61 % along the C7 level, was observed during lifting 75% weight at overhead height in a flexed neck posture.
3) The sternocleidomastoid muscle exerted 12.0, 21.2, and 30.4 N, and the upper trapezius muscle exerted 6.0, 10.6, and 15.2 N forces (unilaterally) at 25% to 50% to 75% weight conditions. The corresponding EMG activation for the sternocleidomastoid and upper trapezius muscles were 3.4% to 4.2% to 6.2% and 7.9%, 13.9%, and 20.0%, respectively.

4) The total compressive forces exerted by the four neck muscles at the C4-C5 level during isometric lifting tasks at elbow height were 72.6 (19.4), 128.5(37.7), and 184.4(56.1) N corresponding to the 25%, 50%, and 75% weight conditions.
5) The sternocleidomastoid muscle worked as hard as the upper trapezius muscle, and therefore occupational studies focusing on the neck MSD due to the forceful arm exertions should evaluate the sternocleidomastoid muscle, in addition to the upper trapezius muscle.
6) Probable physical risk factors associated with the development of neck MSD include:
    - Lifting in extreme neck postures
    - Lifting at higher heights (shoulder and overhead)
    - Lifting heavy weights
7) Workplace design:
    - Evaluations of forceful arm exertions and heavy lifting tasks should include their effects on the cervical region

CHAPTER 9: RECOMMENDATION FOR FUTURE WORK

The results of this dissertation clearly indicate that the neck musculature plays an active role during forceful arm exertions; however, only simple static exertions were evaluated. More complex tasks, common at workplaces involving static as well as dynamic exertions, should be studied. The effect of dynamic loading would be understood further by conducting more sophisticated kinetic, kinematic, and inverse dynamics types of analysis using EMG, 3-D motion, as well as force data. Moreover, future studies, should to be performed at actual work sites, evaluating real tasks and workers.

The forceful exertion would be studied mainly to understand the pathomechanism associated with cervical-disc pathologies such as disc herniation, cervical spondylosis, and cervical myelopathy. On the other hand, the submaximal repetitive and static prolong exertions would be studied to evaluate the development of myalgia. Evaluation of the risk factors in the mix of exposures common in the workplace has been identified as one of the most important future research direction in the National Occupational Research Agenda (NORA). Therefore, in the evaluation of static and dynamic exertions and to better quantify the link between the epidemiological risk and biomechanical loading, significant importance might be given to model the roles of psychosocial stressors and individual characteristics, as well as task specific factors.

From the modeling perspective, the mathematical model formulated in this study could be further expanded to a more realistic model, incorporating all the neck muscles.

The optimization approach used in this research perfectly balances the net joint moment to quantify the muscle forces. This approach ignores the individual muscles' activation strategies. In the future, a model incorporating the activation strategies of individual muscles could be developed, using electromyography data. A more sophisticated hybrid model using electromyography, as well as optimization techniques, could also be developed. Additionally, musculoskeletal modeling software, such as SIMM and Visual 3D, could be used to develop musculoskeletal models using bones, muscles, ligaments, and tendons by incorporating the experimental EMG, motion, and force data. By integrating mathematical models with the musculoskeletal models, clinically significant models of the cervical spine could be developed. Such models could be used for assessment purposes as well as determining pre- and post- treatment modalities.

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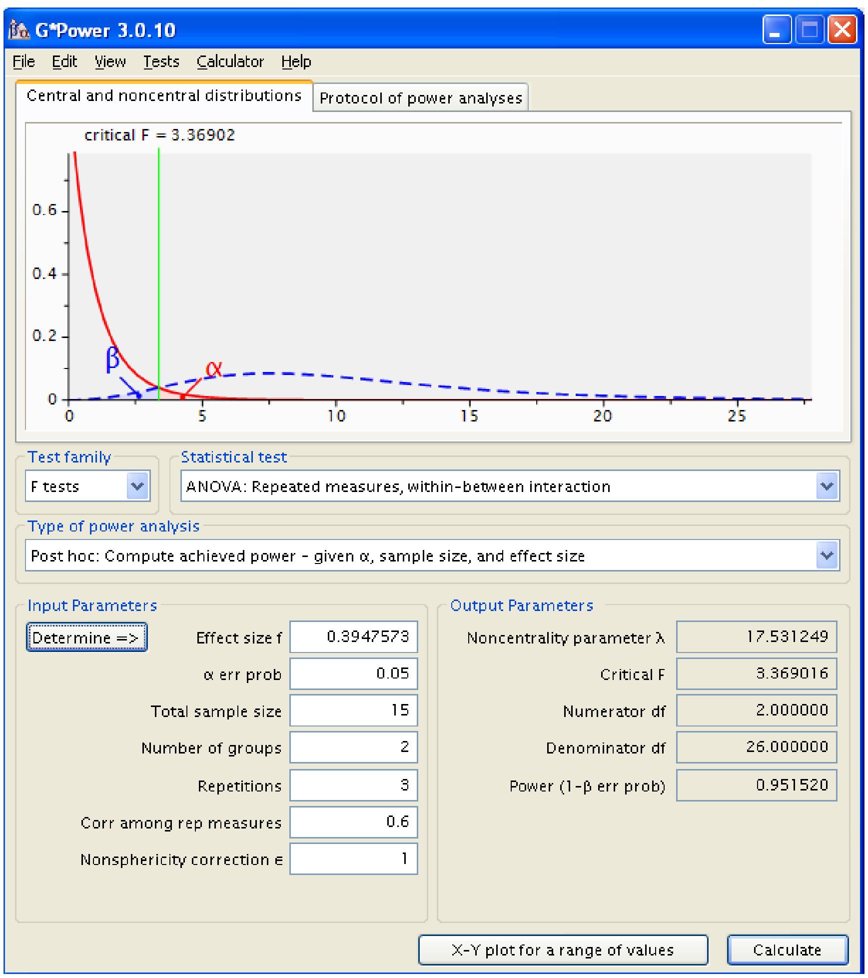
APPENDIX A: POWER CALCULATIONS

The power of the statistics was determined using G*Power 3.0.1 software (Christian-Albrechts-Universität, Germany). To determine the effect size (considering the repeated measures ANOVA) the variance of the within effect was determined using following formula:

$$\sigma_{\mu}^{2} = \frac{(\mu_{ij} - \mu_{25})^2 + (\mu_{ij} - \mu_{50})^2 + (\mu_{ij} - \mu_{75})^2}{3}$$

	25%	50%	75%	mean
Group 1	$X_{1,25}$	$X_{1,50}$	$X_{1,75}$	μ_1
Group 2	$X_{2,25}$	$X_{2,50}$	$X_{2,75}$	μ_1
mean	μ_{25}	μ_{50}	μ_{75}	μ_{ij}

Variance explained by special effect (software input) was set to the and effect size was calculated. The power of the statistics was determined by inputting various other numbers as shown in the following software output:



APPENDIX B: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

Physical Activity Readiness Questionnaire (PAR-Q)

For most people physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.

YES	NO	
☐	☐	1. Has your doctor ever said you have a heart trouble? should only do physical activity recommended by a doctor?
☐	☐	2. Do you frequently suffer from chest pain?
☐	☐	3. Do you often faint or have spells of severe dizziness?
☐	☐	4. Has your doctor ever said your blood pressure was too high?
☐	☐	5. Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by, or might be made worse with exercise.
☐	☐	6. Is there any good physical reason why you should not follow an activity program even if you want to?
☐	☐	7. Are you 65 and not accustomed to vigorous exercise?

If you answer "yes" to any question, vigorous exercise or exercise testing should be postponed. Medical clearance may be necessary.

I have read this questionnaire, I understand it does not provide medical assessment in lieu of a physical examination by a physician.

Participant's signature: _ _ _ _ _ _ _ _ _ _ _ _ _ _ Date: _ _ _ _ _ _ _ _ _ _

Investigatior's signature: _ _ _ _ _ _ _ _ _ _ _ _ _ _ Date: _ _ _ _ _ _ _ _ _ _

Adopted from PAR-Q validation report, British Columbia department of Health, June 1975.

Reference: BQ Hafen, WWK Hoeger (1994), Wellness: Guidelines for a healthy lifestyle. Englewood, Colo.: Morton Pub. Co.

APPENDIX C: IRB APPLICATION AND CONSENT FORM

LSU INSTITUTIONAL REVIEW BOARD (IRB)

IRB APPLICATION: APPROVAL OF PROJECTS WHICH USE HUMAN SUBJECTS

==

(**IRB Use:** IRB# _______ Review Type: Expedited___ Full ___)

==

Part 1: General Information

1. **Principal Investigator:** **Fereydoun Aghazadeh__** Rank: **Assoc.Professor**

    Dept.: **Department of Construction Management and Industrial Engineering**

    E-mail: **aghazadeh@lsu.edu**

2. **Project Title:** **Role of neck muscles during the static and dynamic exertions**

3. **Proposed duration** (months): **24** **Start date:** **March 1, 2007**

4. **Funding sought from**: **NIOSH Small Research Grant Program (ANNOUNCEMENT NO. PAR-06-55, R03)**

5. **LSU Proposal #**: **N.A.** 6. **Number of subjects requested**: **60**

6. **Are you obtaining any health information from a health care provider that contains any of the identifiers listed below**? **NO**

A. Names

B. Address: street address, city, county, precinct, ZIP code, and their equivalent geocodes. Exception for ZIP codes: The initial three digits of the ZIP Code may be used, if according to current publicly available data from the Bureau of the Census: (1) The geographic unit formed by combining all ZIP codes with the same three initial digits contains more than 20,000 people; and (2) the initial three digits of a ZIP code for all such geographic units containing 20,000 or fewer people is changed to '000'. (Note: The 17 currently restricted 3-digit ZIP codes to be replaced with '000' include: 036, 059, 063, 102, 203, 556, 692, 790, 821, 823, 830, 831, 878, 879, 884, 890, and 893.)
C. Dates related to individuals

i. Birth date
ii. Admission date
iii. Discharge date
iv. Date of death
v. And all ages over 89 and all elements of dates (including year) indicative of such age. Such ages and elements may be aggregated into a single category of age 90 or older.
D. Telephone numbers;
E. Fax numbers;
F. Electronic mail addresses;
G. Social security numbers;
H. Medical record numbers; (including prescription numbers and clinical trial numbers)
I. Health plan beneficiary numbers;
J. Account numbers;
K. Certificate/license numbers;
L. Vehicle identifiers and serial numbers including license plate numbers;
M. Device identifiers and serial numbers;
N. Web Universal Resource Locators (URLs);
O. Internet Protocol (IP) address numbers;
P. Biometric identifiers, including finger and voice prints;
Q. Full face photographic images and any comparable images; and
R. Any other unique identifying number, characteristic, or code; except a code used for re-identification purposes; and
S. The facility does not have actual knowledge that the information could be used alone or in combination with other information to identify an individual who is the subject of the information.

YES Your study falls under the HIPAA (Health Information Privacy and Accountability Act) and you must obtain either a limited data set use agreement or a HIPPA authorization agreement from the health care provider. This agreement must be submitted with your IRB protocol.

NO You do not need a HIPAA agreement.

A. ASSURANCE: PRINCIPAL INVESTIGATOR (named above)

I accept personal responsibility for the conduct of this study (including ensuring compliance of co-investigators/co-workers in accordance with the documents submitted herewith and the following guidelines for human subject protection: The Belmont Report, LSU's Assurance with OPRR, and 45 CFR 46 (Available from OSP or at http://www.lsu.edu/irb)

Signature of PI _________________________ Date _____________

Part 2: Project Abstract - provide a brief abstract of the project.

The significant neck pathologies i.e. degenerative disc diseases result from the disorders of the cervical-disc complex. The excessive and repetitive compressive forces acting on the cervical spine are the primary causal factor associated with the degenerative disc diseases. The major neck muscles are coupled to the shoulder and run parallel to the cervical spine. The parallel arrangement of the neck muscles can transmit the forces during the excessive and repetitive contraction of these muscles to the cervical spine. Among the various epidemiologic studies reviewed by the NIOSH in their report on the "Musculoskeletal Disorders (MSD) and Workplace Factors" an evidence for forceful arm and hand exertion and neck MSD was found. However no previous experimental study considers the roles of these muscles in the lifting activities involving forceful or repetitive arm exertions. The purpose of the current study is to understand the role of neck muscles in the static and dynamic lifting activities. The EMG activities of upper trapezius (posterior neck muscle) and sternocleidomastoid (anterior neck muscle) will be recorded during the static and dynamic lifting tasks

Part 3: Research Protocol

A: Describe study procedures

Two studies will be conducted to examine the roles of the neck muscles during the static and dynamic lifting tasks. During first experiment, each participant will perform a static lifting task. The task will involve holding a rectangular box (46cm x 30cm x16cm) at elbow height in the sagittal plane with the upper arm parallel to the truck (abducted 0 degrees) and forearm flexed 90 degrees. Three lifting weights will be utilized for each participant. The lifting weights used will be the 50%, 75% and 100% of the individual participant's static arm lift strength. The participants will perform the lifting trials with their neck at the neutral, flexed and extended positions.

During second experiment, each participant will perform a dynamic lifting task. The task will be consist of lifting a rectangular box (46cm x 30cm x16cm) with cutout handles, from the knuckle height to the shoulder height along the mid sagittal plane. The participants will stand at a comfortable distance (35-50 cm) directly in front of the load with his feet placed symmetrically and comfortably apart. The origin and the end point of the lift will be alone the same plane perpendicular to the participant's mid sagittal plane. The task will require the lifting only and no manual lowering will be required. Each participant will perform 4 lifts at three different neck positions. The lifting weight used will be the 50% of individual participant's static arm lift strength.

The procedure to determine the static arm lift strength:
A custom made apparatus consist of handle coupled to the load cell will be utilized to measure the static arm lift strength. The participant will stand erect in front of the

handle, with legs and back straight. The height of the handle will be adjusted such that the forearms are flexed 90 degrees, i.e., perpendicular to the subject's torso. The upper arms will be vertical; parallel and adjacent to the torso. The participant will hold sides of the handle by hands; exert force upward and vertical using his/her arm muscles only. The participants will be instructed to apply force slowly and steadily (without a jerk), until the maximum exertion is reached. The resulting strength will be recorded as static arm lift strength.

B: Answer each of the following questions.

1. Why is the use of human subjects necessary? (v.s. animals/in vitro)

The primary purpose of the current study is to understand the role of neck muscle in the static and dynamic lifting activities. The major neck muscles run parallel to the cervical spine and are coupled to the shoulders. The coupling of the major neck muscles to the shoulder may require these muscles to a play role in supporting the shoulder during forceful arm exertions. If these muscles contract corresponding to the forceful arm exertions then due to their anatomical arrangement i.e. parallel to the cervical spine, these forces may affect the cervical spine compressive forces. Thus current research is to understand biomechanics of human neck muscles; hence the use of human subjects is necessary.

2. Specify sites of data collection.

Human Factors Lab
3412 CEBA
Department of construction management and Industrial Engineering
Louisiana State University Baton Rouge, LA 70803

B2 Gym - Armory Building
Department of Kinesiology
Louisiana State University Baton Rouge, LA 70803

3. If surgical or invasive procedures are used, give name, address, and telephone number of supervising physician and the qualifications of the person(s) performing the procedures. Comparable information when qualified participation or supervision is required or appropriate.

No surgical or invasive procedures will be used for this study.

4. Provide the names, dosage, and actions of any drugs or other materials administered to the subjects and the qualifications of the person(s) administering the drugs.

No Drugs or materials will be administered to the subjects.

5. Detail all the physical, psychological, and social risks to which the subjects may be exposed.

There are no risks involved in performing in the proposed experiments. During static lifting tasks participants will lift 50%, 75% and 100% of their own predetermined strengths, while during the dynamic lifting tasks predetermined psychophysical strength will be used as lifting weights. Also the duration of force application is very small during both the static and dynamic lifting tasks.

6. What steps will be taken to minimize risks to subjects?

Minimum risk of muscle or ligament strain as well as disc injury is possible. Carrying out following steps will further minimize these minimal risks:

1) During the static arm lift strength determination each participant will stand erect in front of the handle, with legs and back straight. The height of the handle will be adjusted such that the forearms are flexed 90 degrees, i.e., perpendicular to the subject's torso. The upper arms will be vertical; parallel and adjacent to the torso. The participant will hold sides of the handle by hands; exert force upward and vertical using his/her arm muscles only. The participants will be instructed to apply force slowly and steadily (without a jerk), until the maximum exertion is reached.

2) The risk of muscle or ligament strain and the disc injury during the static task (experiment 1) will be minimized by using 50%, 75% and 100% of the individual participant's own static arm lift strength. Also the exertions will be performed for a minimal duration of 10 seconds.

3) During the dynamic tasks (experiment 2) the participants will lift the weight equivalent to 50% of their static arm lift strength, which is approximately equal to the 100 pounds for the healthy population. Only 4 lifts will be performed during each trial.

We have been using the proposed protocol to determine the static arm lift strength and the lifting weights equal to 50% of individual's static arm lift strength to test various lifting tasks in the sagittal plane and never encountered any incidences of injuries.

Moreover all the subjects who will not meet the physical requirements and will answer "YES" to the following health-screening questionnaire will be excluded.

1) Has your doctor ever said you have heart trouble?
2) Do you frequently have pains in your heart or chest?

3) Do you often feel faint or have spells of severe dizziness?
4) Has your doctor ever said your blood pressure was too high?
5) Has your doctor ever told you that you have a bone or joint problem, arthritis that has been aggravated by exercise, or might be made worse with exercise?
6) Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to?
7) Have you ever had back, neck or shoulder pain, or spinal/disk surgery?

In case of any physical injury to participants during this research project, treatment is not available at Louisiana State University, nor is there any insurance carried by the University or its personnel applicable to cover any such injury. Treatment and financial compensation for such injury must be provided through the participant's own insurance program. In case of emergency, the local emergency service (911) will be contacted.

7. Describe the recruitment pool (community, institution, group) and the criteria used to select and exclude subjects.

A recruitment advertisement will be posted to request volunteers. Both genders as well as Minorities will be included according to the proportion of the local community.

8. List any vulnerable population whose members are included in this project (e.g., children under the age of 18; mentally impaired persons; pregnant women; prisoners; the aged.)

This study will recruit graduate or undergraduate students at Louisiana state university between the ages of 20 and 35 who are free from neck and shoulder pain and have no musculoskeletal abnormalities. Thus no vulnerable population will be included in the current study.

9. Describe the process through which informed consent will be obtained.(Informed consent usually requires an oral explanation,discussion, and opportunity for questions before seeking consent form signature.)

Prior to the study, the researchers will ensure that the subjects have read, understood and signed the consent forms made available to them. The researchers will explain orally the detailed procedure of the experimental task. Any questions from the participants will be answered before proceeding with the survey.

10. (A) Is this study anonymous or confidential?
(Anonymous means that the identity of the subjects is never linked to the data,directly, or indirectly through a code system.)
(B) If a confidential study, detail how will the privacy of the subjects and security of their data will be protected.

All the information gathered will be kept confidential and locked in the file cabinet at Dr. Aghazadeh's office. Each subject will be assigned a subject ID to ensure that no personally identifiable information will be linked to the subject. Results of this study will be submitted for publication without any subject identifiable information by using assigned subject ID. Any videos/photos taken during this study will not be used in published materials and/or for educational purposes without the subject's permission. If photos are used, all efforts will be made by the researchers to block out the face of the individual if requested by the subject. All the relevant data will be kept five years after the project is completed and will be destroyed by the project researchers thereafter.

Part 4: Consent Form

1. Study Title:	Role of neck muscles in the static and dynamic lifting activities
2. Performance Site:	3412, Human Factors Lab Department of construction management and Industrial Engineering , Louisiana State University and Agricultural and Mechanical College B2 Gym - Armory Building Department of Kinesiology Louisiana State University Baton Rouge, LA 70803
3. Investigators:	Dr. F Aghazadeh Department of construction management and Industrial Engineering 3132B CEBA, Louisiana State University Baton Rouge, LA 70803 Telephone Number: (225)578-5367
4. Purpose of the Study:	The purpose of the current study is to understand the role of neck muscles in the static and dynamic lifting activities. The EMG activities of upper trapezius (posterior neck muscle) and sternocleidomastoid (anterior neck muscle) will be recorded for static and dynamic lifting tasks EMG stands for Electromyography. It involves measuring the activities of the muscles by measuring the electrical signal. The signal is acquired by using bipolar surface electrodes placed directly on the skin.

During the current protocol, disposable pre-gelled surface electrodes will be placed on the neck muscles and EMG signal will be recorded (in millivolts) using a data acquisition system.

5. Subject Inclusion:	Graduate or undergraduate students at Louisiana state university between the ages of 20 and 35 who are free from neck and shoulder pain and have no musculoskeletal abnormalities will be recruited for the current study. Participants who answer YES to any of the following questions will be excluded from the research. 1) Has your doctor ever said you have heart trouble? 2) Do you frequently have pains in your heart or chest? 3) Do you often feel faint or have spells of severe dizziness? 4) Has your doctor ever said your blood pressure was too high? 5) Has your doctor ever told you that you have a bone or joint problem, arthritis that has been aggravated by exercise, or might be made worse with exercise? 6) Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to? 7) Have you ever had back, neck or shoulder pain, or spinal/disk surgery?
6. Number of subjects:	60
7. Study Procedures:	The study procedure will be completely explained to the subject and all the questions regarding the research will be answered. Participants will be asked to read and sign the consent form before the start of experiment. During first experiment, each participant will perform a static lifting task. The task will involve holding a rectangular box (46cm x 30cm x16cm) at elbow height in the sagittal plane with the upper arm parallel to the truck (abducted 0 degrees) and forearm flexed 90 degrees. Three lifting weights will be utilized for each participant. The lifting weights used will be the 50%, 75% and 100% of the individual participant's static arm lift strength. The participants will perform

the lifting trials with their neck in the neutral, flexed and extended positions.

During second experiment, each participant will perform a dynamic lifting task. The task will be consist of lifting a rectangular box (46cm x 30cm x16cm) with cutout handles, from the knuckle height to the shoulder height along the mid sagittal plane. The participants will stand at a comfortable distance (35-50 cm) directly in front of the load with his feet placed symmetrically and comfortably apart. The origin and the end point of the lift will be alone the same plane perpendicular to the participant's mid sagittal plane. The task will require the lifting only and no manual lowering will be required. Each participant will perform 4 lifts at three different neck positions. The lifting weight used will be the 50% individual participant's static arm lift strength.

The procedure to determine the static arm lift strength:

A custom made apparatus consist of handle coupled to the load cell will be utilized to measure the static arm lift strength. The participant will stand erect in front of the handle, with legs and back straight. The height of the handle will be adjusted such that the forearms are flexed 90 degrees, i.e., perpendicular to the subject's torso. The upper arms will be vertical; parallel and adjacent to the torso. The participant will hold sides of the handle by hands; exert force upward and vertical using his/her arm muscles only. The participants will be instructed to apply force slowly and steadily (without a jerk), until the maximum exertion is reached. The resulting strength will be recorded as static arm lift strength.

8. Benefits: There will not be any direct health, monetary or mental benefits to the individual participant. But the results of the study may be beneficial to the greater population as it leads to a better understanding of the role of neck muscles in cervical spine disorders.

9. Risks:

Minimum risk of muscle or ligament strain as well as disc injury is possible. Carrying out following steps will further minimize these minimal risks:

1) During the static arm lift strength determination each participant will stand erect, with legs and back straight and hold the handle such that the forearms are flexed 90^0, i.e., perpendicular to the subject's torso and the upper arms are vertical; parallel and adjacent to the torso. The participants will be instructed to exert the upward force gradually without any jerk.

2) The risk of muscle or ligament strain and the disc injury during the static task (experiment 1) will be minimized by using 50%, 75% and 100% of the individual participant's own static arm lift strength. Also the exertions will be performed for a minimal duration of 10 seconds.

3) During the dynamic tasks (experiment 2) the participants will lift the weight equivalent to 50% of their static arm lift strength, which is approximately equal to the 100 pounds for the healthy population. Only perform 4 lifts will be performed during each trial.

10. Measures to reduce the risk:

As explained above, the risk of lifting injuries during the static lifting tasks will be minimized by using individual's predetermined lifting strengths. Also for dynamic lifting tasks, only 50% of individual's static arm lift strength will be used as the lifting weight. The approximate static arm lift strength for the healthy populations is around 100.00 pounds. We have been using the proposed protocol to determine the static arm lift strength and the lifting weights equal to 50% of individual's static arm lift strength to test various lifting tasks in the sagittal plane and never encountered any incidences of injuries.

Moreover all the subjects who will not meet the physical requirements and will answer, "YES" to the health-screening questionnaire (explained above) will be excluded. In case of any physical injury to participants during this research project, treatment is not available at Louisiana State University, nor is there any insurance carried by the University or its personnel applicable to cover any such injury. Treatment and financial compensation for such injury must be provided through the participant's own insurance program. In case of emergency, the local emergency service (911) will be contacted.

10. Right to Refuse: Subjects may choose not to participate or if at any time during the study, subject feels uncomfortable with any method or performing the requirements, formal withdrawal from the study will commence at any time without any penalty.

11. Privacy: If the results of present study will get published, names or identifying information of the subjects will not be included in the publication. Subject identity will remain secret unless disclosure is required by law. The data will be stored in a locked cabinet or password-secured computer. The screening questionnaires of rejected subjects will be destroyed.

12. Financial Information: No costs are incurred by subjects in this study.

Signatures:

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Chairman, LSU Institutional Review Board, (225)578-8692. I agree to participate in the study described above and acknowledge the researchers' obligation to provide me with a copy of this consent form if signed by me.

Subject Signature ____________________________ Date ______________________

The study subject has indicated to me that he/she is unable to read. I certify that I have read this consent form to the subject and explained that by completing the signature line above, the subject has agreed to participate.

Signature of Reader _______________________________Date ______________________

APPENDIX D: VISUAL BASIC MACROS

1) EMG data trimming, Demean and fullwave rectification

```
Sub transfer()
a = 4000
sum1 = 0
sum2 = 0
sum3 = 0
sum4 = 0
sum5 = 0
sum6 = 0
sum7 = 0
sum8 = 0

Sheet2.Cells(1, 2) = "R-SCM Lower"
Sheet2.Cells(1, 3) = "R-SCM Upper"
Sheet2.Cells(1, 4) = "L-SCM Lower"
Sheet2.Cells(1, 5) = "L-SCM Upper"
Sheet2.Cells(1, 6) = "R-TRP Lower"
Sheet2.Cells(1, 7) = "R-TRP Upper"
Sheet2.Cells(1, 8) = "L-TRP Lower"
Sheet2.Cells(1, 9) = "L-TRP Upper"

 For i = 1 To 6000 'transfer data to sheet 2
   Sheet2.Cells(i + 1, 1) = (i / 1000)
   Sheet2.Cells(i + 1, 2) = Sheet1.Cells(a + i, 2)
   Sheet2.Cells(i + 1, 3) = Sheet1.Cells(a + i, 3)
   Sheet2.Cells(i + 1, 4) = Sheet1.Cells(a + i, 4)
   Sheet2.Cells(i + 1, 5) = Sheet1.Cells(a + i, 5)
   Sheet2.Cells(i + 1, 6) = Sheet1.Cells(a + i, 6)
   Sheet2.Cells(i + 1, 7) = Sheet1.Cells(a + i, 7)
   Sheet2.Cells(i + 1, 8) = Sheet1.Cells(a + i, 8)
   Sheet2.Cells(i + 1, 9) = Sheet1.Cells(a + i, 9)
   Next i

         For i = 1 To 6000 'calculate column average
         sum1 = sum1 + Sheet2.Cells(i + 1, 2)
         sum2 = sum2 + Sheet2.Cells(i + 1, 3)
         sum3 = sum3 + Sheet2.Cells(i + 1, 4)
         sum4 = sum4 + Sheet2.Cells(i + 1, 5)
         sum5 = sum5 + Sheet2.Cells(i + 1, 6)
         sum6 = sum6 + Sheet2.Cells(i + 1, 7)
         sum7 = sum7 + Sheet2.Cells(i + 1, 8)
         sum8 = sum8 + Sheet2.Cells(i + 1, 9)
         Next i
```

```
    avg1 = sum1 / 6000
    avg2 = sum2 / 6000
    avg3 = sum3 / 6000
    avg4 = sum4 / 6000
    avg5 = sum5 / 6000
    avg6 = sum6 / 6000
    avg7 = sum7 / 6000
    avg8 = sum8 / 6000

    Sheet2.Cells(6003, 2) = avg1
    Sheet2.Cells(6003, 3) = avg2
    Sheet2.Cells(6003, 4) = avg3
    Sheet2.Cells(6003, 5) = avg4
    Sheet2.Cells(6003, 6) = avg5
    Sheet2.Cells(6003, 7) = avg6
    Sheet2.Cells(6003, 8) = avg7
    Sheet2.Cells(6003, 9) = avg8

        For i = 1 To 6000 'Demean and fullwave rectification the data
        Sheet2.Cells(i + 1, 11) = Sheet2.Cells(i + 1, 2) - avg1
        Sheet2.Cells(i + 1, 12) = Sheet2.Cells(i + 1, 3) - avg2
        Sheet2.Cells(i + 1, 13) = Sheet2.Cells(i + 1, 4) - avg3
        Sheet2.Cells(i + 1, 14) = Sheet2.Cells(i + 1, 5) - avg4
        Sheet2.Cells(i + 1, 15) = Sheet2.Cells(i + 1, 6) - avg5
        Sheet2.Cells(i + 1, 16) = Sheet2.Cells(i + 1, 7) - avg6
        Sheet2.Cells(i + 1, 17) = Sheet2.Cells(i + 1, 8) - avg7
        Sheet2.Cells(i + 1, 18) = Sheet2.Cells(i + 1, 9) - avg8

        Sheet2.Cells(i + 1, 20) = Abs(Sheet2.Cells(i + 1, 11))
        Sheet2.Cells(i + 1, 21) = Abs(Sheet2.Cells(i + 1, 12))
        Sheet2.Cells(i + 1, 22) = Abs(Sheet2.Cells(i + 1, 13))
        Sheet2.Cells(i + 1, 23) = Abs(Sheet2.Cells(i + 1, 14))
        Sheet2.Cells(i + 1, 24) = Abs(Sheet2.Cells(i + 1, 15))
        Sheet2.Cells(i + 1, 25) = Abs(Sheet2.Cells(i + 1, 16))
        Sheet2.Cells(i + 1, 26) = Abs(Sheet2.Cells(i + 1, 17))
        Sheet2.Cells(i + 1, 27) = Abs(Sheet2.Cells(i + 1, 18))
        Next i

End Sub
```

2) Low pass Butterworth filter

```
Sub DFilter1()
'Following are the variables needed to be defined outside
'of the sub in order to get the sub "DFilter" to operate
Const DFNumpnt = 6000      ' Number of points in the set of data being passed in
Const f1 = 5, f2 = 50
Const DFPi = 3.1415926
Const DFcutoff = 4      ' Cutoff frequency for either a hi-pass or a low-pass
Const DFfiltertype = "lp"  ' can be either "lp" for low pass or "hp" for high pass
Const DFSrate = 1000       'Sampling rate of the original date
Const DFtypef = "Butterworth"
Dim DFti    ' time interval (period) of the original data, 1/sampling rate
Dim DFpcut
Dim DFWC
Dim DFk1, DFk2, DFk3
Dim DFa0, DFa1, DFa2
Dim DFb1, DFb2
Dim DFfiltoption As String
ReDim DFdata(DFNumpnt)    ' original data set need to be passed in to the sub
ReDim DFnewdata(DFNumpnt) ' Filtered data at the end of the sub
ReDim DFTemp(1 To DFNumpnt + 4), DFprime(1 To DFNumpnt + 4) As Single
'generate data
For DFi = 2 To DFNumpnt
   DFdata(DFi) = Cells(DFi, 20)  '10 * Sin(1 + 2 * DFPi * f1 * DFi / 1000) + 5 * Sin(2 +
2 * DFPi * f2 * DFi / 1000)
Next DFi
'Fourth order, zero lag filter
'correction to cutoff for high-pass filter
DFfiltoption = DFfiltertype
DFti = 1 / DFSrate
If DFfiltoption = "hp" Then
   DFpcut = (1 / (2 * DFti)) - DFcutoff
Else
   DFpcut = DFcutoff
End If
DFWC = Tan(DFPi * DFpcut * DFti)
'Wc need to be corrected for the dual pass
'Murphy and Robertson (1994),
'J. of Applied Biomechanics, 10:374-381
'And also, Robertson, Barden and Dowling
'NACOB II, 1992
If DFtypef = "Butterworth" Then
   DFWC = DFWC / Sqr(Sqr(Sqr(2) - 1))
```

```
Else
   DFWC = DFWC / Sqr(Sqr(Sqr(2)) - 1)
End If
If DFtypef = "Butterworth" Then
   DFk1 = Sqr(2) * DFWC
Else
   DFk1 = 2 * DFWC
End If
DFk2 = DFWC ^ 2
DFa0 = DFk2 / (1 + DFk1 + DFk2)
DFa1 = 2 * DFa0
DFa2 = DFa0
DFk3 = (2 * DFa0) / DFk2
DFb1 = (-2 * DFa0) + DFk3
DFb2 = 1 - (2 * DFa0) - DFk3
'correction to coefficients for high-pass filter
If DFfiltoption = "hp" Then
   DFa1 = -DFa1
   DFb1 = -DFb1
End If
'Filter
DFTemp(1) = DFdata(1) + (DFdata(1) - DFdata(2))
DFTemp(2) = DFdata(1) + (DFdata(1) - DFdata(3))
DFTemp(DFNumpnt + 4) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 1))
DFTemp(DFNumpnt + 3) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 2))
For DFi = 1 To DFNumpnt
   DFTemp(DFi + 2) = DFdata(DFi)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFprime(DFi) = DFTemp(DFi)
Next DFi
For DFi = 3 To DFNumpnt + 4
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi - 1) + DFa2 *
DFTemp(DFi - 2) + DFb1 * DFprime(DFi - 1) + DFb2 * DFprime(DFi - 2)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFTemp(DFi) = DFprime(DFi)
Next DFi
For DFi = DFNumpnt + 2 To 1 Step -1
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi + 1) + DFa2 *
DFTemp(DFi + 2) + DFb1 * DFprime(DFi + 1) + DFb2 * DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
```

```
   DFnewdata(DFi) = DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
   'Cells(DFi, 1) = DFi
   'Cells(DFi, 2) = DFdata(DFi)
   Cells(DFi, 29) = DFnewdata(DFi)
Next DFi
'*********************************************************************
ReDim DFdata(DFNumpnt)    ' original data set need to be passed in to the sub
ReDim DFnewdata(DFNumpnt) ' Filtered data at the end of the sub
ReDim DFTemp(1 To DFNumpnt + 4), DFprime(1 To DFNumpnt + 4) As Single
'generate data
For DFi = 2 To DFNumpnt
   DFdata(DFi) = Cells(DFi, 21)  '10 * Sin(1 + 2 * DFPi * f1 * DFi / 1000) + 5 * Sin(2 +
2 * DFPi * f2 * DFi / 1000)
Next DFi

DFfiltoption = DFfiltertype
DFti = 1 / DFSrate
If DFfiltoption = "hp" Then
   DFpcut = (1 / (2 * DFti)) - DFcutoff
Else
   DFpcut = DFcutoff
End If
DFWC = Tan(DFPi * DFpcut * DFti)

If DFtypef = "Butterworth" Then
   DFWC = DFWC / Sqr(Sqr(Sqr(2) - 1))
Else
   DFWC = DFWC / Sqr(Sqr(Sqr(2)) - 1)
End If
If DFtypef = "Butterworth" Then
   DFk1 = Sqr(2) * DFWC
Else
   DFk1 = 2 * DFWC
End If
DFk2 = DFWC ^ 2
DFa0 = DFk2 / (1 + DFk1 + DFk2)
DFa1 = 2 * DFa0
DFa2 = DFa0
DFk3 = (2 * DFa0) / DFk2
DFb1 = (-2 * DFa0) + DFk3
DFb2 = 1 - (2 * DFa0) - DFk3

If DFfiltoption = "hp" Then
```

```
   DFa1 = -DFa1
   DFb1 = -DFb1
End If
'Filter
DFTemp(1) = DFdata(1) + (DFdata(1) - DFdata(2))
DFTemp(2) = DFdata(1) + (DFdata(1) - DFdata(3))
DFTemp(DFNumpnt + 4) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 1))
DFTemp(DFNumpnt + 3) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 2))
For DFi = 1 To DFNumpnt
   DFTemp(DFi + 2) = DFdata(DFi)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFprime(DFi) = DFTemp(DFi)
Next DFi
For DFi = 3 To DFNumpnt + 4
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi - 1) + DFa2 *
DFTemp(DFi - 2) + DFb1 * DFprime(DFi - 1) + DFb2 * DFprime(DFi - 2)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFTemp(DFi) = DFprime(DFi)
Next DFi
For DFi = DFNumpnt + 2 To 1 Step -1
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi + 1) + DFa2 *
DFTemp(DFi + 2) + DFb1 * DFprime(DFi + 1) + DFb2 * DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
   DFnewdata(DFi) = DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
   'Cells(DFi, 1) = DFi
   'Cells(DFi, 2) = DFdata(DFi)
   Cells(DFi, 30) = DFnewdata(DFi)
Next DFi
'*******************************************************************
ReDim DFdata(DFNumpnt)    ' original data set need to be passed in to the sub
ReDim DFnewdata(DFNumpnt) ' Filtered data at the end of the sub
ReDim DFTemp(1 To DFNumpnt + 4), DFprime(1 To DFNumpnt + 4) As Single
'generate data
For DFi = 2 To DFNumpnt
   DFdata(DFi) = Cells(DFi, 22)  '10 * Sin(1 + 2 * DFPi * f1 * DFi / 1000) + 5 * Sin(2 +
2 * DFPi * f2 * DFi / 1000)
Next DFi
DFfiltoption = DFfiltertype
```

```
DFti = 1 / DFSrate
If DFfiltoption = "hp" Then
   DFpcut = (1 / (2 * DFti)) - DFcutoff
Else
   DFpcut = DFcutoff
End If
DFWC = Tan(DFPi * DFpcut * DFti)

If DFtypef = "Butterworth" Then
   DFWC = DFWC / Sqr(Sqr(Sqr(2) - 1))
Else
   DFWC = DFWC / Sqr(Sqr(Sqr(2)) - 1)
End If
If DFtypef = "Butterworth" Then
   DFk1 = Sqr(2) * DFWC
Else
   DFk1 = 2 * DFWC
End If
DFk2 = DFWC ^ 2
DFa0 = DFk2 / (1 + DFk1 + DFk2)
DFa1 = 2 * DFa0
DFa2 = DFa0
DFk3 = (2 * DFa0) / DFk2
DFb1 = (-2 * DFa0) + DFk3
DFb2 = 1 - (2 * DFa0) - DFk3
'correction to coefficients for high-pass filter
If DFfiltoption = "hp" Then
   DFa1 = -DFa1
   DFb1 = -DFb1
End If
'Filter
DFTemp(1) = DFdata(1) + (DFdata(1) - DFdata(2))
DFTemp(2) = DFdata(1) + (DFdata(1) - DFdata(3))
DFTemp(DFNumpnt + 4) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 1))
DFTemp(DFNumpnt + 3) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 2))
For DFi = 1 To DFNumpnt
   DFTemp(DFi + 2) = DFdata(DFi)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFprime(DFi) = DFTemp(DFi)
Next DFi
For DFi = 3 To DFNumpnt + 4
```

```
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi - 1) + DFa2 *
DFTemp(DFi - 2) + DFb1 * DFprime(DFi - 1) + DFb2 * DFprime(DFi - 2)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFTemp(DFi) = DFprime(DFi)
Next DFi
For DFi = DFNumpnt + 2 To 1 Step -1
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi + 1) + DFa2 *
DFTemp(DFi + 2) + DFb1 * DFprime(DFi + 1) + DFb2 * DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
   DFnewdata(DFi) = DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
   Cells(DFi, 31) = DFnewdata(DFi)
Next DFi
'*****************************************************************
ReDim DFdata(DFNumpnt)    ' original data set need to be passed in to the sub
ReDim DFnewdata(DFNumpnt) ' Filtered data at the end of the sub
ReDim DFTemp(1 To DFNumpnt + 4), DFprime(1 To DFNumpnt + 4) As Single
'generate data
For DFi = 2 To DFNumpnt
   DFdata(DFi) = Cells(DFi, 23)  '10 * Sin(1 + 2 * DFPi * f1 * DFi / 1000) + 5 * Sin(2 +
2 * DFPi * f2 * DFi / 1000)
Next DFi
'Fourth order, zero lag filter
'correction to cutoff for high-pass filter
DFfiltoption = DFfiltertype
DFti = 1 / DFSrate
If DFfiltoption = "hp" Then
   DFpcut = (1 / (2 * DFti)) - DFcutoff
Else
   DFpcut = DFcutoff
End If
DFWC = Tan(DFPi * DFpcut * DFti)

If DFtypef = "Butterworth" Then
   DFWC = DFWC / Sqr(Sqr(Sqr(2) - 1))
Else
   DFWC = DFWC / Sqr(Sqr(Sqr(2)) - 1)
End If
If DFtypef = "Butterworth" Then
   DFk1 = Sqr(2) * DFWC
Else
   DFk1 = 2 * DFWC
```

```
End If
DFk2 = DFWC ^ 2
DFa0 = DFk2 / (1 + DFk1 + DFk2)
DFa1 = 2 * DFa0
DFa2 = DFa0
DFk3 = (2 * DFa0) / DFk2
DFb1 = (-2 * DFa0) + DFk3
DFb2 = 1 - (2 * DFa0) - DFk3
'correction to coefficients for high-pass filter
If DFfiltoption = "hp" Then
   DFa1 = -DFa1
   DFb1 = -DFb1
End If
'Filter
DFTemp(1) = DFdata(1) + (DFdata(1) - DFdata(2))
DFTemp(2) = DFdata(1) + (DFdata(1) - DFdata(3))
DFTemp(DFNumpnt + 4) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 1))
DFTemp(DFNumpnt + 3) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 2))
For DFi = 1 To DFNumpnt
   DFTemp(DFi + 2) = DFdata(DFi)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFprime(DFi) = DFTemp(DFi)
Next DFi
For DFi = 3 To DFNumpnt + 4
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi - 1) + DFa2 *
DFTemp(DFi - 2) + DFb1 * DFprime(DFi - 1) + DFb2 * DFprime(DFi - 2)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFTemp(DFi) = DFprime(DFi)
Next DFi
For DFi = DFNumpnt + 2 To 1 Step -1
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi + 1) + DFa2 *
DFTemp(DFi + 2) + DFb1 * DFprime(DFi + 1) + DFb2 * DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
   DFnewdata(DFi) = DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
   Cells(DFi, 32) = DFnewdata(DFi)
Next DFi
'*********************************************************************
ReDim DFdata(DFNumpnt)    ' original data set need to be passed in to the sub
```

```
ReDim DFnewdata(DFNumpnt) ' Filtered data at the end of the sub
ReDim DFTemp(1 To DFNumpnt + 4), DFprime(1 To DFNumpnt + 4) As Single
'generate data
For DFi = 2 To DFNumpnt
   DFdata(DFi) = Cells(DFi, 24)  '10 * Sin(1 + 2 * DFPi * f1 * DFi / 1000) + 5 * Sin(2 +
2 * DFPi * f2 * DFi / 1000)
Next DFi

DFfiltoption = DFfiltertype
DFti = 1 / DFSrate
If DFfiltoption = "hp" Then
   DFpcut = (1 / (2 * DFti)) - DFcutoff
Else
   DFpcut = DFcutoff
End If
DFWC = Tan(DFPi * DFpcut * DFti)

If DFtypef = "Butterworth" Then
   DFWC = DFWC / Sqr(Sqr(Sqr(2) - 1))
Else
   DFWC = DFWC / Sqr(Sqr(Sqr(2)) - 1)
End If
If DFtypef = "Butterworth" Then
   DFk1 = Sqr(2) * DFWC
Else
   DFk1 = 2 * DFWC
End If
DFk2 = DFWC ^ 2
DFa0 = DFk2 / (1 + DFk1 + DFk2)
DFa1 = 2 * DFa0
DFa2 = DFa0
DFk3 = (2 * DFa0) / DFk2
DFb1 = (-2 * DFa0) + DFk3
DFb2 = 1 - (2 * DFa0) - DFk3
If DFfiltoption = "hp" Then
   DFa1 = -DFa1
   DFb1 = -DFb1
End If
'Filter
DFTemp(1) = DFdata(1) + (DFdata(1) - DFdata(2))
DFTemp(2) = DFdata(1) + (DFdata(1) - DFdata(3))
DFTemp(DFNumpnt + 4) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 1))
DFTemp(DFNumpnt + 3) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 2))
```

```
For DFi = 1 To DFNumpnt
   DFTemp(DFi + 2) = DFdata(DFi)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFprime(DFi) = DFTemp(DFi)
Next DFi
For DFi = 3 To DFNumpnt + 4
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi - 1) + DFa2 *
DFTemp(DFi - 2) + DFb1 * DFprime(DFi - 1) + DFb2 * DFprime(DFi - 2)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFTemp(DFi) = DFprime(DFi)
Next DFi
For DFi = DFNumpnt + 2 To 1 Step -1
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi + 1) + DFa2 *
DFTemp(DFi + 2) + DFb1 * DFprime(DFi + 1) + DFb2 * DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
   DFnewdata(DFi) = DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
   Cells(DFi, 33) = DFnewdata(DFi)
Next DFi
'*******************************************************************
ReDim DFdata(DFNumpnt)    ' original data set need to be passed in to the sub
ReDim DFnewdata(DFNumpnt) ' Filtered data at the end of the sub
ReDim DFTemp(1 To DFNumpnt + 4), DFprime(1 To DFNumpnt + 4) As Single
'generate data
For DFi = 2 To DFNumpnt
   DFdata(DFi) = Cells(DFi, 25)  '10 * Sin(1 + 2 * DFPi * f1 * DFi / 1000) + 5 * Sin(2 +
2 * DFPi * f2 * DFi / 1000)
Next DFi
DFfiltoption = DFfiltertype
DFti = 1 / DFSrate
If DFfiltoption = "hp" Then
   DFpcut = (1 / (2 * DFti)) - DFcutoff
Else
   DFpcut = DFcutoff
End If
DFWC = Tan(DFPi * DFpcut * DFti)
If DFtypef = "Butterworth" Then
   DFWC = DFWC / Sqr(Sqr(Sqr(2) - 1))
Else
   DFWC = DFWC / Sqr(Sqr(Sqr(2)) - 1)
End If
```

```
If DFtypef = "Butterworth" Then
   DFk1 = Sqr(2) * DFWC
Else
   DFk1 = 2 * DFWC
End If
DFk2 = DFWC ^ 2
DFa0 = DFk2 / (1 + DFk1 + DFk2)
DFa1 = 2 * DFa0
DFa2 = DFa0
DFk3 = (2 * DFa0) / DFk2
DFb1 = (-2 * DFa0) + DFk3
DFb2 = 1 - (2 * DFa0) - DFk3
If DFfiltoption = "hp" Then
   DFa1 = -DFa1
   DFb1 = -DFb1
End If
'Filter
DFTemp(1) = DFdata(1) + (DFdata(1) - DFdata(2))
DFTemp(2) = DFdata(1) + (DFdata(1) - DFdata(3))
DFTemp(DFNumpnt + 4) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 1))
DFTemp(DFNumpnt + 3) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 2))
For DFi = 1 To DFNumpnt
   DFTemp(DFi + 2) = DFdata(DFi)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFprime(DFi) = DFTemp(DFi)
Next DFi
For DFi = 3 To DFNumpnt + 4
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi - 1) + DFa2 *
DFTemp(DFi - 2) + DFb1 * DFprime(DFi - 1) + DFb2 * DFprime(DFi - 2)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFTemp(DFi) = DFprime(DFi)
Next DFi
For DFi = DFNumpnt + 2 To 1 Step -1
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi + 1) + DFa2 *
DFTemp(DFi + 2) + DFb1 * DFprime(DFi + 1) + DFb2 * DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
   DFnewdata(DFi) = DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
   Cells(DFi, 34) = DFnewdata(DFi)
```

```
Next DFi
'*********************************************************************
ReDim DFdata(DFNumpnt)    ' original data set need to be passed in to the sub
ReDim DFnewdata(DFNumpnt) ' Filtered data at the end of the sub
ReDim DFTemp(1 To DFNumpnt + 4), DFprime(1 To DFNumpnt + 4) As Single
'generate data
For DFi = 2 To DFNumpnt
   DFdata(DFi) = Cells(DFi, 26)  '10 * Sin(1 + 2 * DFPi * f1 * DFi / 1000) + 5 * Sin(2 +
2 * DFPi * f2 * DFi / 1000)
Next DFi

DFfiltoption = DFfiltertype
DFti = 1 / DFSrate
If DFfiltoption = "hp" Then
   DFpcut = (1 / (2 * DFti)) - DFcutoff
Else
   DFpcut = DFcutoff
End If
DFWC = Tan(DFPi * DFpcut * DFti)

If DFtypef = "Butterworth" Then
   DFWC = DFWC / Sqr(Sqr(Sqr(2) - 1))
Else
   DFWC = DFWC / Sqr(Sqr(Sqr(2)) - 1)
End If
If DFtypef = "Butterworth" Then
   DFk1 = Sqr(2) * DFWC
Else
   DFk1 = 2 * DFWC
End If
DFk2 = DFWC ^ 2
DFa0 = DFk2 / (1 + DFk1 + DFk2)
DFa1 = 2 * DFa0
DFa2 = DFa0
DFk3 = (2 * DFa0) / DFk2
DFb1 = (-2 * DFa0) + DFk3
DFb2 = 1 - (2 * DFa0) - DFk3
If DFfiltoption = "hp" Then
   DFa1 = -DFa1
   DFb1 = -DFb1
End If
'Filter
DFTemp(1) = DFdata(1) + (DFdata(1) - DFdata(2))
DFTemp(2) = DFdata(1) + (DFdata(1) - DFdata(3))
```

```
DFTemp(DFNumpnt + 4) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 1))
DFTemp(DFNumpnt + 3) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 2))
For DFi = 1 To DFNumpnt
   DFTemp(DFi + 2) = DFdata(DFi)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFprime(DFi) = DFTemp(DFi)
Next DFi
For DFi = 3 To DFNumpnt + 4
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi - 1) + DFa2 *
DFTemp(DFi - 2) + DFb1 * DFprime(DFi - 1) + DFb2 * DFprime(DFi - 2)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFTemp(DFi) = DFprime(DFi)
Next DFi
For DFi = DFNumpnt + 2 To 1 Step -1
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi + 1) + DFa2 *
DFTemp(DFi + 2) + DFb1 * DFprime(DFi + 1) + DFb2 * DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
   DFnewdata(DFi) = DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
   Cells(DFi, 35) = DFnewdata(DFi)
Next DFi
'*********************************************************************
ReDim DFdata(DFNumpnt)    ' original data set need to be passed in to the sub
ReDim DFnewdata(DFNumpnt) ' Filtered data at the end of the sub
ReDim DFTemp(1 To DFNumpnt + 4), DFprime(1 To DFNumpnt + 4) As Single
'generate data
For DFi = 2 To DFNumpnt
   DFdata(DFi) = Cells(DFi, 27)  '10 * Sin(1 + 2 * DFPi * f1 * DFi / 1000) + 5 * Sin(2 +
2 * DFPi * f2 * DFi / 1000)
Next DFi
DFfiltoption = DFfiltertype
DFti = 1 / DFSrate
If DFfiltoption = "hp" Then
   DFpcut = (1 / (2 * DFti)) - DFcutoff
Else
   DFpcut = DFcutoff
End If
DFWC = Tan(DFPi * DFpcut * DFti)
```

```
If DFtypef = "Butterworth" Then
   DFWC = DFWC / Sqr(Sqr(Sqr(2) - 1))
Else
   DFWC = DFWC / Sqr(Sqr(Sqr(2)) - 1)
End If
If DFtypef = "Butterworth" Then
   DFk1 = Sqr(2) * DFWC
Else
   DFk1 = 2 * DFWC
End If
DFk2 = DFWC ^ 2
DFa0 = DFk2 / (1 + DFk1 + DFk2)
DFa1 = 2 * DFa0
DFa2 = DFa0
DFk3 = (2 * DFa0) / DFk2
DFb1 = (-2 * DFa0) + DFk3
DFb2 = 1 - (2 * DFa0) - DFk3
'correction to coefficients for high-pass filter
If DFfiltoption = "hp" Then
   DFa1 = -DFa1
   DFb1 = -DFb1
End If
'Filter
DFTemp(1) = DFdata(1) + (DFdata(1) - DFdata(2))
DFTemp(2) = DFdata(1) + (DFdata(1) - DFdata(3))
DFTemp(DFNumpnt + 4) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 1))
DFTemp(DFNumpnt + 3) = DFdata(DFNumpnt) + (DFdata(DFNumpnt) -
DFdata(DFNumpnt - 2))
For DFi = 1 To DFNumpnt
   DFTemp(DFi + 2) = DFdata(DFi)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFprime(DFi) = DFTemp(DFi)
Next DFi
For DFi = 3 To DFNumpnt + 4
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi - 1) + DFa2 *
DFTemp(DFi - 2) + DFb1 * DFprime(DFi - 1) + DFb2 * DFprime(DFi - 2)
Next DFi
For DFi = 1 To DFNumpnt + 4
   DFTemp(DFi) = DFprime(DFi)
Next DFi
For DFi = DFNumpnt + 2 To 1 Step -1
   DFprime(DFi) = DFa0 * DFTemp(DFi) + DFa1 * DFTemp(DFi + 1) + DFa2 *
DFTemp(DFi + 2) + DFb1 * DFprime(DFi + 1) + DFb2 * DFprime(DFi + 2)
```

```
Next DFi
For DFi = 1 To DFNumpnt
   DFnewdata(DFi) = DFprime(DFi + 2)
Next DFi
For DFi = 1 To DFNumpnt
   Cells(DFi, 36) = DFnewdata(DFi)
Next DFi
End Sub
```

<u>3) Determination of MAV</u>

```
Sub transfer2()
a = 1000
sum1 = 0
sum2 = 0
sum3 = 0
sum4 = 0
sum5 = 0
sum6 = 0
sum7 = 0
sum8 = 0

Sheet3.Cells(1, 2) = "R-SCM Lower"
Sheet3.Cells(1, 3) = "R-SCM Upper"
Sheet3.Cells(1, 4) = "L-SCM Lower"
Sheet3.Cells(1, 5) = "L-SCM Upper"
Sheet3.Cells(1, 6) = "R-TRP Lower"
Sheet3.Cells(1, 7) = "R-TRP Upper"
Sheet3.Cells(1, 8) = "L-TRP Lower"
Sheet3.Cells(1, 9) = "L-TRP Upper"

Sheet3.Cells(1, 10) = "R-SCM Lower"
Sheet3.Cells(1, 11) = "R-SCM Upper"
Sheet3.Cells(1, 12) = "L-SCM Lower"
Sheet3.Cells(1, 13) = "L-SCM Upper"
Sheet3.Cells(1, 14) = "R-TRP Lower"
Sheet3.Cells(1, 15) = "R-TRP Upper"
Sheet3.Cells(1, 16) = "L-TRP Lower"
Sheet3.Cells(1, 17) = "L-TRP Upper"

 For i = 1 To 5000 'transfer data to sheet 2
   Sheet3.Cells(i + 1, 1) = (i / 1000)
   Sheet3.Cells(i + 1, 2) = Sheet2.Cells(a + i, 29)
   Sheet3.Cells(i + 1, 3) = Sheet2.Cells(a + i, 30)
   Sheet3.Cells(i + 1, 4) = Sheet2.Cells(a + i, 31)
```

```
    Sheet3.Cells(i + 1, 5) = Sheet2.Cells(a + i, 32)
    Sheet3.Cells(i + 1, 6) = Sheet2.Cells(a + i, 33)
    Sheet3.Cells(i + 1, 7) = Sheet2.Cells(a + i, 34)
    Sheet3.Cells(i + 1, 8) = Sheet2.Cells(a + i, 35)
    Sheet3.Cells(i + 1, 9) = Sheet2.Cells(a + i, 36)
Next i
'End Sub
'Sub max()

    For i = 1 To 5000 'average magnitude
        sum1 = sum1 + Sheet3.Cells(i + 1, 2)
        sum2 = sum2 + Sheet3.Cells(i + 1, 3)
        sum3 = sum3 + Sheet3.Cells(i + 1, 4)
        sum4 = sum4 + Sheet3.Cells(i + 1, 5)
        sum5 = sum5 + Sheet3.Cells(i + 1, 6)
        sum6 = sum6 + Sheet3.Cells(i + 1, 7)
        sum7 = sum7 + Sheet3.Cells(i + 1, 8)
        sum8 = sum8 + Sheet3.Cells(i + 1, 9)
    Next i
        avg1 = sum1 / 5000
        avg2 = sum2 / 5000
        avg3 = sum3 / 5000
        avg4 = sum4 / 5000
        avg5 = sum5 / 5000
        avg6 = sum6 / 5000
        avg7 = sum7 / 5000
        avg8 = sum8 / 5000

        Sheet3.Cells(2, 10) = "Average"
        Sheet3.Cells(5, 10) = "Maximum"
        Sheet3.Cells(3, 10) = avg1
        Sheet3.Cells(3, 11) = avg2
        Sheet3.Cells(3, 12) = avg3
        Sheet3.Cells(3, 13) = avg4
        Sheet3.Cells(3, 14) = avg5
        Sheet3.Cells(3, 15) = avg6
        Sheet3.Cells(3, 16) = avg7
        Sheet3.Cells(3, 17) = avg8


x = Sheet3.Cells(2, 2)
For i = 1 To 5000 'transfer data to sheet 2
    If Sheet3.Cells(i + 1, 2) > x Then
    x = Sheet3.Cells(i + 1, 2)
    End If
```

```
Next i
   Sheet3.Cells(6, 10) = x

x = Sheet3.Cells(2, 3)
For i = 1 To 5000 'transfer data to sheet 2
   If Sheet3.Cells(i + 1, 3) > x Then
   x = Sheet3.Cells(i + 1, 3)
   End If
Next i
   Sheet3.Cells(6, 11) = x

x = Sheet3.Cells(2, 4)
For i = 1 To 5000 'transfer data to sheet 2
   If Sheet3.Cells(i + 1, 4) > x Then
   x = Sheet3.Cells(i + 1, 4)
   End If
Next i
   Sheet3.Cells(6, 12) = x

x = Sheet3.Cells(2, 5)
For i = 1 To 5000 'transfer data to sheet 2
   If Sheet3.Cells(i + 1, 5) > x Then
   x = Sheet3.Cells(i + 1, 5)
   End If
Next i
   Sheet3.Cells(6, 13) = x

x = Sheet3.Cells(2, 6)
For i = 1 To 5000 'transfer data to sheet 2
   If Sheet3.Cells(i + 1, 6) > x Then
   x = Sheet3.Cells(i + 1, 6)
   End If
Next i
   Sheet3.Cells(6, 14) = x

x = Sheet3.Cells(2, 7)
For i = 1 To 5000 'transfer data to sheet 2
   If Sheet3.Cells(i + 1, 7) > x Then
   x = Sheet3.Cells(i + 1, 7)
   End If
Next i
   Sheet3.Cells(6, 15) = x

 x = Sheet3.Cells(2, 8)
For i = 1 To 5000 'transfer data to sheet 2
```

```
   If Sheet3.Cells(i + 1, 8) > x Then
   x = Sheet3.Cells(i + 1, 8)
   End If
Next i
   Sheet3.Cells(6, 16) = x

   x = Sheet3.Cells(2, 9)
For i = 1 To 5000 'transfer data to sheet 2
   If Sheet3.Cells(i + 1, 9) > x Then
   x = Sheet3.Cells(i + 1, 9)
   End If
Next i
   Sheet3.Cells(6, 17) = x

End Sub
'***************************************************************
```

4) Determination of N-MAV

```
Sub normalize()
'Dim a, b, c, d, e, f, g, h As String

Dim xlApp As New Excel.Application
Dim wb As Excel.Workbook
Dim ws As Excel.Worksheet
Set wb = xlApp.Workbooks.Open("G:\summer 2008 Dessertation data analysis\subject8
excel\N-shd ht sub8\used trial\summary")
Set ws = wb.Sheets("Sheet1")
a = ws.Cells(15, 12).Value
b = ws.Cells(15, 13).Value
c = ws.Cells(15, 14).Value
d = ws.Cells(15, 15).Value
e = ws.Cells(15, 16).Value
f = ws.Cells(15, 17).Value
g = ws.Cells(15, 18).Value
h = ws.Cells(15, 19).Value

Set wb = Nothing
Set ws = Nothing
Set xlApp = Nothing

ActiveWorkbook.Activate
Sheet3.Cells(8, 10) = a
Sheet3.Cells(8, 11) = b
Sheet3.Cells(8, 12) = c
```

```
Sheet3.Cells(8, 13) = d
Sheet3.Cells(8, 14) = e
Sheet3.Cells(8, 15) = f
Sheet3.Cells(8, 16) = g
Sheet3.Cells(8, 17) = h

For i = 1 To 5000
Sheet3.Cells(i + 1, 20) = Sheet3.Cells(i + 1, 2) / a
Sheet3.Cells(i + 1, 21) = Sheet3.Cells(i + 1, 3) / b
Sheet3.Cells(i + 1, 22) = Sheet3.Cells(i + 1, 4) / c
Sheet3.Cells(i + 1, 23) = Sheet3.Cells(i + 1, 5) / d
Sheet3.Cells(i + 1, 24) = Sheet3.Cells(i + 1, 6) / e
Sheet3.Cells(i + 1, 25) = Sheet3.Cells(i + 1, 7) / f
Sheet3.Cells(i + 1, 26) = Sheet3.Cells(i + 1, 8) / g
Sheet3.Cells(i + 1, 27) = Sheet3.Cells(i + 1, 9) / h
Next i
End Sub
```

APPENDIX E: ANTHROPOMETRIC AND STRENGTH DATA

Participant no	1	2	3	4	5	6	7	8	9	10
Age	28	23	21	22	20	22	19	23	28	22
Gender	Male	Male	Male	Male	Male	Male	Male	Male	Male	Male
Weight (lb)	213.8	178.6	174.2	186.0	181.0	180.8	132.3	205.0	264.6	189.0
Height (cm)	180.3	174.0	175.0	180.0	179.8	185.0	177.8	178.0	168.0	180.3
neck depth	12.4	11.4	11	11.6	12	11.1	10.8	12.1	13.9	10.8
neck width (M-L)	12.2	11.5	11.2	11	11.8	11.1	11.6	12.35	13.7	10.8
Elbow height maximum isometric lifting strength (lb)	75	71	54	52	75	42	44	72	54	46
Shoulder height maximum isometric lifting strength (lb)	31	29	36	22	41	32	23	36	21	28
Overhead height maximum isometric lifting strength (lb)	72	58	60	45	72	44	60	60	51	51
Overhead maximum isometric pulling strength (lb)	87	65	80	52	52	46	59.66	82	115	79
Shoulder height maximum isometric pushing strength (lb)	48	70	74	49	61	54	42	54	77	65
Shoulder height maximum isometric pulling strength (lb)	64	65	80	53	46	56	48	52	120	100

Participant no	11	12	13	14	15	16	17	18	19	20
Age	28	23	22	32	21	21	30	21	21	22
Gender	Male	Male	Male	Male	Male	Female	Female	Female	Female	Female
Weight (lb)	201.0	146.6	178.6	180.8	176.4	114.6	127.9	184.0	136.7	165.3
Height (cm)	195.0	170.5	175.4	179.6	181.5	170.2	157.5	154.9	165.5	160.5
neck depth	12.33	11	11.7	11.8	12	8.3	9.6	10.2	10.5	10.4
neck width (M-L)	12	11.6	11.4	12.3	12	8.9	9.9	11.5	10.8	9.7
Elbow height maximum isometric lifting strength (lb)	46	52	35	52	72	22	27	28	37	33
Shoulder height maximum isometric lifting strength (lb)	29	27	23	38	45	16	34	16	25	28
Overhead height maximum isometric lifting strength (lb)	69	56	36	63	104	38	26	38	43	37
Overhead maximum isometric pulling strength (lb)	73	55	40	82	100	32	21	42	47	47
Shoulder height maximum isometric pushing strength (lb)	100	100	48	100	112	38	16	28	79	39
Shoulder height maximum isometric pulling strength (lb)	83	68	44	69	87	41	28	38	58	42

Participant no	21	22	23	24	25	26	27	28	29	30
Age	22	25	23	22	24	22	22	22	21	24
Gender	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
Weight (lb)	116.8	121.3	167.6	131.2	142.2	198.4	152.0	120.2	115.7	132.3
Height (cm)	149.7	168.0	163.5	171.5	169.2	159.8	159.5	160.5	154.0	165.0
neck depth	9.4	9.6	9.8	9	9.7	9.9	10.2	9.1	9.7	9.9
neck width (M-L)	10.2	9.9	10.1	9.7	9.3	10.2	11.2	9.6	9.3	9.5
Elbow height maximum isometric lifting strength (lb)	39.3	35	55	43	41	35	36	37	34	35
Shoulder height maximum isometric lifting strength (lb)	21	20	22	22	25	18	17	20.33	20	19
Overhead height maximum isometric lifting strength (lb)	52	37	72	47	45	34	28	33.33	38	35
Overhead maximum isometric pulling strength (lb)	57	40	75	78	56	56	35	47	43	40
Shoulder height maximum isometric pushing strength (lb)	39	48	86	80	82	86	35.6	76.6	42.33	50
Shoulder height maximum isometric pulling strength (lb)	39	44	75	74	75	69	39	54	42	42

APPENDIX F: N-MAV DATA

Task 1: Lifting at elbow height

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
1	Male	25	Ext	10.7	8.4	7.5	16	Female	6.8	15.7	7.1
1	Male	25	Flx	1.1	7.0	18.8	16	Female	13.7	25.3	19.6
1	Male	25	Neu	2.1	16.9	29.7	16	Female	10.8	11.9	7.3
1	Male	50	Ext	13.5	23.4	17.5	16	Female	10.1	19.4	8.5
1	Male	50	Flx	6.5	29.8	22.6	16	Female	9.6	24.4	18.5
1	Male	50	Neu	6.0	20.5	15.7	16	Female	9.0	20.5	11.1
1	Male	75	Ext	13.1	33.0	22.3	16	Female	14.3	26.4	10.6
1	Male	75	Flx	8.7	43.0	36.4	16	Female	15.7	30.9	21.9
1	Male	75	Neu	7.2	29.6	23.2	16	Female	13.2	20.9	10.8
2	Male	25	Ext	4.0	6.8	11.0	17	Female	17.6	2.7	8.2
2	Male	25	Flx	1.6	8.8	7.5	17	Female	7.7	6.4	8.3
2	Male	25	Neu	1.3	7.3	8.1	17	Female	7.4	2.9	8.0
2	Male	50	Ext	5.3	16.8	13.8	17	Female	29.5	18.3	10.3
2	Male	50	Flx	1.5	11.5	7.5	17	Female	9.1	14.7	9.2
2	Male	50	Neu	1.6	10.3	8.3	17	Female	8.5	9.1	8.2
2	Male	75	Ext	4.5	12.6	13.2	17	Female	40.5	23.2	12.4
2	Male	75	Flx	3.2	21.2	19.0	17	Female	7.3	16.7	8.7
2	Male	75	Neu	3.1	12.5	14.9	17	Female	8.0	15.6	9.5
3	Male	25	Ext	2.4	8.2	10.2	18	Female	12.9	5.7	16.0
3	Male	25	Flx	0.8	6.5	17.1	18	Female	9.2	10.1	20.5
3	Male	25	Neu	0.9	6.3	10.6	18	Female	7.2	7.6	16.5
3	Male	50	Ext	3.8	11.5	12.9	18	Female	13.2	10.3	17.8
3	Male	50	Flx	1.2	13.5	16.7	18	Female	7.4	7.2	18.6
3	Male	50	Neu	1.1	12.5	14.3	18	Female	9.8	10.2	18.9
3	Male	75	Ext	5.5	19.3	19.9	18	Female	27.9	11.1	22.3
3	Male	75	Flx	1.5	19.9	25.7	18	Female	10.5	13.7	24.3
3	Male	75	Neu	1.2	11.0	13.7	18	Female	11.4	7.8	18.6
4	Male	25	Ext	5.3	12.4	15.8	19	Female	1.8	7.4	7.8

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
4	Male	25	Flx	2.0	6.8	14.1	19	Female	0.8	8.4	6.7
4	Male	25	Neu	1.6	16.6	18.0	19	Female	0.6	8.6	7.5
4	Male	50	Ext	5.3	19.6	18.8	19	Female	4.2	10.7	12.9
4	Male	50	Flx	1.9	24.6	19.4	19	Female	1.0	15.0	13.0
4	Male	50	Neu	1.7	22.6	23.7	19	Female	0.9	16.2	14.4
4	Male	75	Ext	7.5	35.0	23.2	19	Female	6.0	18.1	21.2
4	Male	75	Flx	2.1	44.8	37.0	19	Female	1.1	29.1	28.2
4	Male	75	Neu	2.4	36.0	31.0	19	Female	1.4	24.2	25.1
5	Male	25	Ext	3.3	17.6	10.0	20	Female	49.3	23.1	4.3
5	Male	25	Flx	3.7	21.0	10.8	20	Female	12.8	33.0	7.5
5	Male	25	Neu	2.4	19.0	9.4	20	Female	8.2	23.7	4.7
5	Male	50	Ext	4.5	26.3	14.1	20	Female	64.0	30.7	5.1
5	Male	50	Flx	4.1	45.0	17.2	20	Female	10.7	26.8	5.9
5	Male	50	Neu	3.0	36.9	14.0	20	Female	8.9	31.5	5.1
5	Male	75	Ext	12.8	27.9	28.6	20	Female	62.4	41.4	6.7
5	Male	75	Flx	4.9	54.8	19.6	20	Female	14.9	44.7	9.0
5	Male	75	Neu	3.4	33.8	20.2	20	Female	8.9	33.2	5.4
6	Male	25	Ext	5.1	13.5	12.8	21	Female	16.7	9.4	14.0
6	Male	25	Flx	3.6	21.9	11.8	21	Female	2.5	15.6	27.6
6	Male	25	Neu	2.8	11.5	14.3	21	Female	4.3	10.1	19.1
6	Male	50	Ext	4.0	20.1	17.9	21	Female	21.1	17.5	25.8
6	Male	50	Flx	7.5	33.6	20.4	21	Female	5.8	24.8	39.8
6	Male	50	Neu	3.5	22.7	14.6	21	Female	9.5	15.3	31.8
6	Male	75	Ext	7.2	31.4	23.4	21	Female	20.2	20.3	30.3
6	Male	75	Flx	9.3	38.4	26.8	21	Female	2.8	32.9	10.3
6	Male	75	Neu	5.5	29.0	24.9	21	Female	7.4	20.8	37.1
7	Male	25	Ext	18.0	11.6	9.3	22	Female	80.3	13.4	8.3
7	Male	25	Flx	2.5	10.4	7.0	22	Female	5.1	22.1	12.6
7	Male	25	Neu	2.1	6.7	7.6	22	Female	7.7	3.7	4.8
7	Male	50	Ext	26.9	23.7	18.2	22	Female	91.9	11.6	9.8

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
7	Male	50	Flx	4.7	20.1	15.2	22	Female	7.7	24.7	18.9
7	Male	50	Neu	2.5	19.5	15.2	22	Female	11.6	18.4	17.5
7	Male	75	Ext	37.2	31.4	32.4	22	Female	94.9	18.1	19.9
7	Male	75	Flx	5.8	32.3	29.1	22	Female	23.4	31.7	30.0
7	Male	75	Neu	3.1	26.5	23.7	22	Female	41.0	19.0	27.6
8	Male	25	Ext	1.0	24.4	8.6	23	Female	24.7	13.4	9.5
8	Male	25	Flx	0.9	21.3	13.2	23	Female	1.7	25.1	16.5
8	Male	25	Neu	0.9	23.8	8.9	23	Female	1.6	6.3	8.0
8	Male	50	Ext	1.2	36.0	12.9	23	Female	22.7	22.2	15.2
8	Male	50	Flx	0.9	33.4	11.1	23	Female	2.9	50.0	37.2
8	Male	50	Neu	1.2	39.6	17.1	23	Female	5.4	23.0	18.6
8	Male	75	Ext	2.3	41.8	24.3	23	Female	32.2	30.7	22.0
8	Male	75	Flx	3.1	65.0	29.5	23	Female	7.3	48.8	37.8
8	Male	75	Neu	3.2	77.5	32.7	23	Female	9.5	29.3	31.1
9	Male	25	Ext	3.1	9.5	5.0	24	Female	8.6	3.5	5.3
9	Male	25	Flx	3.2	13.4	15.9	24	Female	1.5	12.7	17.2
9	Male	25	Neu	3.0	13.7	16.2	24	Female	1.3	6.1	7.8
9	Male	50	Ext	3.2	8.2	17.4	24	Female	11.8	11.5	10.5
9	Male	50	Flx	3.1	18.7	17.7	24	Female	1.9	14.3	20.3
9	Male	50	Neu	3.0	17.3	17.0	24	Female	1.4	11.3	10.3
9	Male	75	Ext	4.1	19.3	29.1	24	Female	17.3	18.6	15.5
9	Male	75	Flx	3.2	21.8	18.0	24	Female	9.6	20.0	25.8
9	Male	75	Neu	3.1	20.2	17.6	24	Female	4.0	18.4	17.8
10	Male	25	Ext	35.9	5.9	19.3	25	Female	4.6	6.6	10.6
10	Male	25	Flx	5.2	8.6	24.9	25	Female	1.4	8.0	21.3
10	Male	25	Neu	3.7	7.4	18.1	25	Female	1.1	3.8	12.7
10	Male	50	Ext	49.0	8.8	28.3	25	Female	7.1	7.9	20.2
10	Male	50	Flx	4.4	12.5	30.2	25	Female	1.5	10.8	29.1
10	Male	50	Neu	4.6	9.8	22.4	25	Female	2.0	7.7	18.8
10	Male	75	Ext	58.2	10.3	38.2	25	Female	9.3	11.7	21.0

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
10	Male	75	Flx	5.9	12.4	27.5	25	Female	1.9	14.6	31.7
10	Male	75	Neu	5.8	13.6	28.1	25	Female	2.3	9.0	20.7
11	Male	25	Ext	13.3	2.8	7.4	26	Female	12.3	24.7	8.1
11	Male	25	Flx	3.6	3.4	11.4	26	Female	4.4	36.4	15.7
11	Male	25	Neu	4.2	2.5	7.7	26	Female	5.2	26.5	11.0
11	Male	50	Ext	20.3	3.9	9.0	26	Female	13.1	54.1	15.0
11	Male	50	Flx	3.4	4.4	13.0	26	Female	4.2	36.3	19.7
11	Male	50	Neu	4.5	5.2	8.8	26	Female	5.9	36.4	16.0
11	Male	75	Ext	18.2	5.6	9.5	26	Female	19.9	70.1	30.8
11	Male	75	Flx	5.0	17.0	25.9	26	Female	6.2	42.5	23.8
11	Male	75	Neu	6.0	5.8	12.4	26	Female	7.8	48.6	18.4
12	Male	25	Ext	4.2	6.1	8.2	27	Female	1.6	18.0	14.8
12	Male	25	Flx	1.3	7.2	7.4	27	Female	2.0	21.0	14.1
12	Male	25	Neu	1.3	7.5	8.2	27	Female	1.4	16.1	11.1
12	Male	50	Ext	4.5	8.1	11.7	27	Female	2.0	12.5	17.3
12	Male	50	Flx	1.5	11.5	10.1	27	Female	2.6	17.9	15.9
12	Male	50	Neu	1.7	10.3	12.6	27	Female	1.7	19.5	15.5
12	Male	75	Ext	8.0	13.1	14.9	27	Female	18.2	7.1	11.7
12	Male	75	Flx	2.3	17.4	18.1	27	Female	2.7	46.1	43.6
12	Male	75	Neu	2.9	12.5	14.9	27	Female	2.9	31.8	28.5
13	Male	25	Ext	18.6	8.5	17.3	28	Female	23.3	9.8	8.5
13	Male	25	Flx	2.1	33.4	25.9	28	Female	1.5	21.2	14.0
13	Male	25	Neu	3.2	25.3	17.2	28	Female	2.3	18.9	6.5
13	Male	50	Ext	16.0	25.0	20.6	28	Female	37.5	31.2	17.3
13	Male	50	Flx	2.2	38.1	27.3	28	Female	3.0	35.1	27.7
13	Male	50	Neu	3.6	35.1	30.7	28	Female	5.3	26.4	12.1
13	Male	75	Ext	20.6	33.9	26.8	28	Female	48.1	38.6	19.9
13	Male	75	Flx	2.4	40.6	37.8	28	Female	3.3	43.6	33.2
13	Male	75	Neu	3.5	40.2	28.2	28	Female	4.3	33.1	14.5
14	Male	25	Ext	1.2	11.5	6.8	29	Female	3.7	1.8	1.9

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
14	Male	25	Flx	1.1	8.9	5.5	29	Female	1.0	27.0	18.2
14	Male	25	Neu	1.0	9.7	5.1	29	Female	0.8	15.5	9.4
14	Male	50	Ext	1.5	11.1	8.9	29	Female	16.3	17.5	12.5
14	Male	50	Flx	1.2	14.8	7.5	29	Female	1.6	33.4	20.2
14	Male	50	Neu	1.1	14.1	8.7	29	Female	0.9	29.3	17.1
14	Male	75	Ext	1.6	17.1	14.5	29	Female	18.8	36.0	23.1
14	Male	75	Flx	1.2	18.9	9.7	29	Female	2.2	55.9	36.8
14	Male	75	Neu	1.2	17.1	10.0	29	Female	1.6	37.9	26.9
15	Male	25	Ext	3.3	0.4	3.3	30	Female	9.8	10.0	8.8
15	Male	25	Flx	4.4	0.5	4.2	30	Female	1.3	22.8	16.9
15	Male	25	Neu	3.1	1.5	6.3	30	Female	0.7	7.0	6.3
15	Male	50	Ext	7.2	2.5	4.4	30	Female	15.0	27.9	21.2
15	Male	50	Flx	6.6	2.2	3.4	30	Female	1.0	42.8	32.1
15	Male	50	Neu	4.6	4.1	21.2	30	Female	0.8	28.1	16.2
15	Male	75	Ext	17.7	4.3	16.8	30	Female	15.9	31.0	22.2
15	Male	75	Flx	7.8	7.7	20.2	30	Female	1.4	55.5	46.7
15	Male	75	Neu	8.2	4.5	15.5	30	Female	1.4	42.7	29.9

Task 2: Lifting at shoulder height

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRPU_C4	Participant no.	Gender	SCM	TRP_C7	TRPU_C4
1	Male	25	Ext	14.0	14.6	7.3	16	Female	48.7	47.5	15.4
1	Male	25	Flx	3.5	22.6	12.9	16	Female	16.3	66.8	37.5
1	Male	25	Neu	3.9	21.4	13.7	16	Female	10.5	52.6	23.0
1	Male	50	Ext	11.2	32.9	17.9	16	Female	40.6	50.8	16.7
1	Male	50	Flx	6.4	46.9	37.3	16	Female	16.5	67.8	43.6
1	Male	50	Neu	5.8	41.2	26.7	16	Female	16.8	57.3	28.3
1	Male	75	Ext	18.1	43.3	23.6	16	Female	56.9	71.4	21.4
1	Male	75	Flx	10.6	60.7	56.5	16	Female	24.3	79.8	49.6

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
1	Male	75	Neu	6.9	48.2	32.1	16	Female	16.2	58.5	29.8
2	Male	25	Ext	19.0	6.4	17.0	17	Female	39.6	32.3	13.0
2	Male	25	Flx	7.5	6.6	15.2	17	Female	8.1	30.6	11.6
2	Male	25	Neu	4.1	6.5	14.3	17	Female	7.8	25.6	10.1
2	Male	50	Ext	11.3	2.8	8.3	17	Female	74.9	58.9	19.2
2	Male	50	Flx	11.9	10.9	19.8	17	Female	11.9	58.8	20.9
2	Male	50	Neu	7.9	9.3	18.0	17	Female	15.2	61.0	22.0
2	Male	75	Ext	31.2	10.8	26.2	17	Female	90.7	60.8	22.8
2	Male	75	Flx	24.5	16.0	38.0	17	Female	16.7	86.8	29.7
2	Male	75	Neu	14.4	14.0	29.8	17	Female	16.9	48.9	17.6
3	Male	25	Ext	6.8	20.6	16.7	18	Female	22.6	13.9	20.3
3	Male	25	Flx	1.2	22.1	21.3	18	Female	7.3	6.9	17.0
3	Male	25	Neu	2.3	25.8	20.6	18	Female	10.6	11.6	18.3
3	Male	50	Ext	9.1	33.5	25.0	18	Female	30.9	18.7	28.4
3	Male	50	Flx	2.1	43.6	36.7	18	Female	14.8	17.9	26.3
3	Male	50	Neu	2.2	39.5	29.9	18	Female	17.9	16.0	24.2
3	Male	75	Ext	10.2	43.2	31.9	18	Female	41.6	20.4	30.4
3	Male	75	Flx	6.6	70.7	50.1	18	Female	17.5	24.7	40.2
3	Male	75	Neu	2.4	45.4	36.4	18	Female	19.5	17.9	25.9
4	Male	25	Ext	4.7	25.8	21.8	19	Female	2.8	10.7	10.5
4	Male	25	Flx	2.1	36.7	31.8	19	Female	0.7	17.5	22.1
4	Male	25	Neu	1.8	26.7	23.8	19	Female	0.9	14.8	15.1
4	Male	50	Ext	3.6	37.8	27.6	19	Female	5.1	12.3	14.6
4	Male	50	Flx	2.4	39.0	31.6	19	Female	1.4	30.4	41.9
4	Male	50	Neu	2.9	39.0	36.6	19	Female	1.2	22.0	24.7
4	Male	75	Ext	5.5	42.0	31.5	19	Female	7.8	28.2	27.9
4	Male	75	Flx	3.1	23.2	35.9	19	Female	2.4	42.7	54.1
4	Male	75	Neu	2.5	40.4	32.9	19	Female	2.8	30.1	36.2
5	Male	25	Ext	6.0	27.9	20.9	20	Female	44.6	52.0	9.0
5	Male	25	Flx	3.2	46.3	36.9	20	Female	17.2	57.7	12.0

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
5	Male	25	Neu	2.2	28.6	25.5	20	Female	11.6	47.6	8.3
5	Male	50	Ext	9.7	84.2	37.8	20	Female	76.4	61.9	10.6
5	Male	50	Flx	4.3	100.4	61.4	20	Female	21.4	74.1	14.4
5	Male	50	Neu	3.5	98.7	61.6	20	Female	12.6	65.0	10.3
5	Male	75	Ext	16.5	110.9	61.8	20	Female	104.4	75.3	12.1
5	Male	75	Flx	6.2	150.1	110.3	20	Female	33.8	92.5	15.4
5	Male	75	Neu	10.3	69.5	68.9	20	Female	20.0	85.0	14.5
6	Male	25	Ext	12.8	37.2	22.9	21	Female	34.0	16.9	30.2
6	Male	25	Flx	5.8	45.8	31.4	21	Female	3.0	21.1	34.5
6	Male	25	Neu	5.4	39.9	29.8	21	Female	7.0	18.6	30.5
6	Male	50	Ext	11.9	42.8	35.6	21	Female	31.3	26.7	46.3
6	Male	50	Flx	10.9	52.5	32.9	21	Female	9.7	47.6	64.4
6	Male	50	Neu	9.1	50.0	37.8	21	Female	11.0	26.5	40.2
6	Male	75	Ext	19.7	52.0	40.7	21	Female	27.1	44.0	63.2
6	Male	75	Flx	16.5	79.0	65.5	21	Female	11.0	38.2	54.0
6	Male	75	Neu	15.7	75.2	58.6	21	Female	16.4	25.9	44.3
7	Male	25	Ext	39.6	39.0	42.4	22	Female	6.1	1.2	7.4
7	Male	25	Flx	8.9	40.1	56.3	22	Female	5.0	1.2	7.5
7	Male	25	Neu	4.1	33.2	32.4	22	Female	5.0	1.3	9.3
7	Male	50	Ext	33.2	63.9	73.3	22	Female	7.3	4.0	3.4
7	Male	50	Flx	8.7	64.1	85.7	22	Female	4.9	1.3	5.8
7	Male	50	Neu	8.7	51.6	65.9	22	Female	7.1	1.2	6.9
7	Male	75	Ext	38.1	90.4	98.7	22	Female	5.1	1.8	8.0
7	Male	75	Flx	3.9	98.5	160.9	22	Female	6.9	8.3	13.7
7	Male	75	Neu	10.9	87.3	110.9	22	Female	5.2	1.2	7.6
8	Male	25	Ext	1.6	57.0	13.6	23	Female	26.1	7.4	9.2
8	Male	25	Flx	1.3	66.2	25.9	23	Female	3.1	27.2	22.4
8	Male	25	Neu	1.2	52.6	17.2	23	Female	2.1	24.8	12.4
8	Male	50	Ext	3.0	81.5	26.7	23	Female	31.9	25.1	18.6
8	Male	50	Flx	2.5	98.5	56.5	23	Female	9.9	55.4	48.2

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
8	Male	50	Neu	2.0	81.5	35.0	23	Female	7.0	39.8	28.9
8	Male	75	Ext	6.5	142.6	47.7	23	Female	50.7	29.8	31.8
8	Male	75	Flx	5.6	154.8	104.1	23	Female	17.5	55.1	52.6
8	Male	75	Neu	4.2	130.7	68.1	23	Female	16.6	41.3	33.4
9	Male	25	Ext	4.6	26.2	5.4	24	Female	18.9	15.5	14.7
9	Male	25	Flx	3.5	30.9	19.7	24	Female	5.1	22.7	25.3
9	Male	25	Neu	3.1	33.4	19.3	24	Female	3.1	19.3	17.1
9	Male	50	Ext	4.4	35.5	22.2	24	Female	30.2	17.2	14.6
9	Male	50	Flx	3.6	35.0	23.9	24	Female	5.4	29.8	32.1
9	Male	50	Neu	3.3	36.2	25.4	24	Female	4.6	19.8	18.3
9	Male	75	Ext	4.2	41.3	26.3	24	Female	35.0	21.4	16.3
9	Male	75	Flx	3.4	42.7	25.1	24	Female	13.5	34.8	35.1
9	Male	75	Neu	3.5	42.3	27.6	24	Female	4.9	20.7	16.3
10	Male	25	Ext	45.6	12.9	30.3	25	Female	8.5	10.2	23.4
10	Male	25	Flx	5.1	16.1	35.3	25	Female	1.4	13.0	31.3
10	Male	25	Neu	4.5	14.8	29.6	25	Female	2.3	8.4	19.8
10	Male	50	Ext	62.7	22.4	48.8	25	Female	15.6	22.8	35.8
10	Male	50	Flx	12.1	26.1	50.4	25	Female	3.5	28.1	48.4
10	Male	50	Neu	16.1	22.2	42.2	25	Female	7.5	25.6	38.1
10	Male	75	Ext	65.0	24.0	59.1	25	Female	14.4	13.7	29.4
10	Male	75	Flx	19.0	34.0	61.2	25	Female	3.6	22.8	44.4
10	Male	75	Neu	23.5	36.6	62.7	25	Female	10.1	34.4	50.2
11	Male	25	Ext	29.3	9.0	8.2	26	Female	17.8	43.8	14.6
11	Male	25	Flx	3.4	9.5	17.5	26	Female	5.0	39.4	15.8
11	Male	25	Neu	4.2	18.8	15.5	26	Female	6.2	33.4	12.2
11	Male	50	Ext	23.5	6.9	11.7	26	Female	27.3	47.4	17.7
11	Male	50	Flx	4.2	13.8	11.2	26	Female	7.7	53.2	21.5
11	Male	50	Neu	4.7	10.5	16.3	26	Female	10.2	51.7	19.2
11	Male	75	Ext	33.7	43.2	25.8	26	Female	24.6	52.0	20.7
11	Male	75	Flx	17.8	29.6	38.6	26	Female	14.8	77.4	33.8

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
11	Male	75	Neu	10.6	36.2	32.7	26	Female	10.4	58.8	24.5
12	Male	25	Ext	6.1	8.7	8.0	27	Female	15.5	26.2	18.7
12	Male	25	Flx	1.4	7.3	6.0	27	Female	2.4	43.5	34.1
12	Male	25	Neu	2.0	7.9	6.8	27	Female	1.7	26.9	16.2
12	Male	50	Ext	6.8	12.2	10.2	27	Female	16.2	35.8	29.4
12	Male	50	Flx	4.7	17.5	17.7	27	Female	2.3	35.0	26.6
12	Male	50	Neu	3.4	13.9	16.3	27	Female	3.0	35.9	29.4
12	Male	75	Ext	12.8	21.2	15.6	27	Female	17.3	36.3	30.1
12	Male	75	Flx	5.7	21.9	20.6	27	Female	4.5	58.3	43.9
12	Male	75	Neu	5.3	14.4	16.4	27	Female	2.7	31.1	23.6
13	Male	25	Ext	47.2	25.1	24.9	28	Female	29.2	15.2	9.9
13	Male	25	Flx	3.6	55.5	52.7	28	Female	3.7	24.4	16.2
13	Male	25	Neu	5.5	36.9	32.7	28	Female	2.0	20.3	7.0
13	Male	50	Ext	42.5	26.0	25.3	28	Female	30.1	16.6	11.4
13	Male	50	Flx	4.9	68.9	63.1	28	Female	5.8	34.2	26.4
13	Male	50	Neu	6.7	55.6	46.4	28	Female	4.4	27.9	10.4
13	Male	75	Ext	46.3	63.9	49.8	28	Female	52.8	23.2	15.0
13	Male	75	Flx	8.1	88.6	83.2	28	Female	4.3	52.7	30.3
13	Male	75	Neu	10.1	51.7	40.7	28	Female	5.8	29.8	11.5
14	Male	25	Ext	1.5	15.5	9.6	29	Female	22.1	46.8	24.0
14	Male	25	Flx	1.2	21.4	9.5	29	Female	1.5	51.8	29.2
14	Male	25	Neu	1.1	23.4	11.5	29	Female	0.9	23.1	12.7
14	Male	50	Ext	2.0	18.7	16.8	29	Female	22.7	44.7	21.7
14	Male	50	Flx	1.5	28.0	18.5	29	Female	1.3	46.8	31.0
14	Male	50	Neu	1.5	25.3	17.5	29	Female	2.8	32.9	19.9
14	Male	75	Ext	4.4	27.6	19.2	29	Female	30.1	50.4	37.5
14	Male	75	Flx	2.4	39.8	26.7	29	Female	3.5	56.8	45.2
14	Male	75	Neu	2.2	36.7	26.1	29	Female	4.6	54.1	41.6
15	Male	25	Ext	15.3	7.3	8.8	30	Female	20.4	34.9	16.4
15	Male	25	Flx	6.9	5.3	7.0	30	Female	1.2	26.4	16.8

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
15	Male	25	Neu	8.0	6.3	18.0	30	Female	0.9	28.4	14.3
15	Male	50	Ext	30.6	9.7	20.9	30	Female	22.8	30.8	15.0
15	Male	50	Flx	14.9	11.0	20.2	30	Female	3.1	60.8	48.2
15	Male	50	Neu	6.1	9.0	16.2	30	Female	1.6	22.0	13.8
15	Male	75	Ext	25.7	11.1	22.7	30	Female	28.8	47.8	34.3
15	Male	75	Flx	19.4	17.1	37.3	30	Female	4.4	71.5	67.1
15	Male	75	Neu	17.1	12.4	29.8	30	Female	3.0	42.7	28.6

Task 3: Lifting at Overhead height

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRPU_C4	Participant no.	Gender	SCM	TRP_C7	TRPU_C4
1	Male	25	Ext	14.4	22.5	15.2	16	Female	80.4	41.0	18.0
1	Male	25	Flx	6.9	31.0	28.3	16	Female	26.3	41.4	18.6
1	Male	25	Neu	4.8	18.9	14.7	16	Female	17.4	33.8	19.4
1	Male	50	Ext	13.4	23.4	34.6	16	Female	99.0	84.0	29.3
1	Male	50	Flx	13.4	48.1	47.7	16	Female	34.1	71.5	50.9
1	Male	50	Neu	7.9	35.1	27.1	16	Female	26.7	71.5	37.3
1	Male	75	Ext	23.5	72.3	80.8	16	Female	117.8	99.5	33.0
1	Male	75	Flx	7.2	3.3	5.8	16	Female	43.0	99.2	82.1
1	Male	75	Neu	12.6	55.9	44.3	16	Female	38.5	96.3	55.7
2	Male	25	Ext	9.4	13.7	12.1	17	Female	24.3	22.6	12.3
2	Male	25	Flx	1.7	17.5	17.7	17	Female	10.3	23.1	11.8
2	Male	25	Neu	3.7	14.0	16.5	17	Female	11.0	18.4	10.3
2	Male	50	Ext	14.0	31.5	19.8	17	Female	77.1	23.6	14.7
2	Male	50	Flx	4.0	26.7	26.5	17	Female	11.7	25.9	12.1
2	Male	50	Neu	6.4	21.4	23.0	17	Female	15.8	34.4	14.1
2	Male	75	Ext	23.0	37.7	44.8	17	Female	71.4	52.0	23.1
2	Male	75	Flx	20.1	43.5	62.7	17	Female	33.5	71.9	31.1
2	Male	75	Neu	9.2	35.1	44.9	17	Female	30.4	52.1	20.1

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
3	Male	25	Ext	13.4	23.9	23.1	18	Female	20.8	11.0	19.9
3	Male	25	Flx	8.0	34.0	32.1	18	Female	8.3	4.9	15.4
3	Male	25	Neu	2.7	29.2	22.5	18	Female	11.7	4.5	15.4
3	Male	50	Ext	13.3	24.7	26.3	18	Female	37.3	20.7	31.4
3	Male	50	Flx	3.9	35.1	28.2	18	Female	17.0	15.4	24.7
3	Male	50	Neu	1.6	27.9	21.8	18	Female	20.6	9.4	21.2
3	Male	75	Ext	19.1	36.8	40.9	18	Female	46.4	28.3	38.6
3	Male	75	Flx	10.8	69.1	87.9	18	Female	27.5	36.2	54.6
3	Male	75	Neu	8.3	46.3	44.7	18	Female	27.3	28.0	42.7
4	Male	25	Ext	5.7	31.0	10.7	19	Female	4.3	12.8	19.2
4	Male	25	Flx	2.1	41.0	17.9	19	Female	1.2	15.4	17.3
4	Male	25	Neu	3.0	34.1	11.2	19	Female	1.0	8.1	9.9
4	Male	50	Ext	9.2	41.7	18.8	19	Female	9.1	21.4	24.4
4	Male	50	Flx	2.6	45.8	21.3	19	Female	2.2	26.4	29.5
4	Male	50	Neu	4.7	42.0	17.1	19	Female	2.2	21.2	26.8
4	Male	75	Ext	8.7	49.2	18.3	19	Female	18.7	30.4	46.1
4	Male	75	Flx	8.1	53.6	31.9	19	Female	5.9	36.5	39.4
4	Male	75	Neu	6.2	61.3	25.4	19	Female	6.2	33.9	48.6
5	Male	25	Ext	8.9	32.4	28.7	20	Female	77.0	40.6	6.6
5	Male	25	Flx	3.8	38.5	22.0	20	Female	16.6	45.4	8.8
5	Male	25	Neu	2.6	19.2	18.2	20	Female	9.8	47.4	6.7
5	Male	50	Ext	11.3	42.1	36.6	20	Female	107.3	53.8	8.7
5	Male	50	Flx	4.6	54.0	42.8	20	Female	20.0	64.7	9.9
5	Male	50	Neu	3.7	51.8	40.3	20	Female	18.1	62.1	9.8
5	Male	75	Ext	15.6	66.7	47.4	20	Female	105.6	54.9	8.5
5	Male	75	Flx	10.1	74.0	53.7	20	Female	24.3	79.6	12.9
5	Male	75	Neu	5.9	61.6	57.0	20	Female	16.2	58.7	8.4
6	Male	25	Ext	13.1	34.4	22.7	21	Female	41.2	21.5	36.1
6	Male	25	Flx	15.7	44.7	27.0	21	Female	9.1	44.0	53.5
6	Male	25	Neu	10.2	31.3	21.3	21	Female	14.2	28.6	40.3

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
6	Male	50	Ext	24.7	41.5	31.9	21	Female	33.7	32.1	48.4
6	Male	50	Flx	19.6	62.4	37.9	21	Female	11.0	41.8	49.2
6	Male	50	Neu	18.4	45.2	39.1	21	Female	13.5	33.1	45.4
6	Male	75	Ext	38.6	63.1	51.6	21	Female	45.1	58.8	85.8
6	Male	75	Flx	22.5	81.1	66.8	21	Female	30.9	71.3	102.6
6	Male	75	Neu	41.3	75.4	70.4	21	Female	28.1	56.1	82.3
7	Male	25	Ext	52.0	50.9	65.3	22	Female	56.3	32.9	20.9
7	Male	25	Flx	17.7	52.9	56.6	22	Female	7.9	41.2	21.7
7	Male	25	Neu	7.8	36.0	30.5	22	Female	18.8	22.6	15.2
7	Male	50	Ext	68.5	50.3	69.5	22	Female	64.8	37.4	17.2
7	Male	50	Flx	30.9	48.8	105.3	22	Female	8.9	55.4	30.8
7	Male	50	Neu	27.8	53.1	115.0	22	Female	30.0	25.8	16.8
7	Male	75	Ext	74.3	59.8	154.2	22	Female	77.7	46.9	21.2
7	Male	75	Flx	63.4	85.0	185.9	22	Female	16.8	60.0	31.9
7	Male	75	Neu	34.8	66.7	102.4	22	Female	32.8	37.5	21.1
8	Male	25	Ext	5.4	87.2	15.4	23	Female	32.8	20.9	15.1
8	Male	25	Flx	1.2	70.3	22.5	23	Female	1.8	41.9	21.2
8	Male	25	Neu	2.0	65.2	20.0	23	Female	1.4	12.4	14.6
8	Male	50	Ext	5.2	91.1	27.3	23	Female	44.9	49.4	34.6
8	Male	50	Flx	2.2	133.7	9.1	23	Female	20.1	66.0	62.2
8	Male	50	Neu	3.2	68.3	25.5	23	Female	12.4	49.4	39.9
8	Male	75	Ext	8.1	101.4	29.6	23	Female	39.2	69.2	42.9
8	Male	75	Flx	6.8	150.1	67.6	23	Female	1.5	13.7	15.3
8	Male	75	Neu	4.4	82.8	34.2	23	Female	24.9	72.1	53.3
9	Male	25	Ext	10.8	23.4	21.4	24	Female	17.1	25.7	17.6
9	Male	25	Flx	4.0	34.0	22.7	24	Female	2.5	17.2	23.6
9	Male	25	Neu	4.4	34.6	22.8	24	Female	1.9	20.7	20.8
9	Male	50	Ext	12.8	32.9	24.2	24	Female	19.8	24.9	22.7
9	Male	50	Flx	4.4	56.0	37.4	24	Female	6.4	32.0	38.4
9	Male	50	Neu	10.8	45.1	33.9	24	Female	3.1	21.1	22.0

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
9	Male	75	Ext	12.1	39.5	27.0	24	Female	29.2	40.7	35.1
9	Male	75	Flx	7.0	44.3	31.7	24	Female	14.6	45.9	58.0
9	Male	75	Neu	9.4	36.8	25.7	24	Female	11.0	34.6	38.9
10	Male	25	Ext	46.3	10.4	26.4	25	Female	11.5	12.4	15.1
10	Male	25	Flx	3.9	12.1	24.9	25	Female	7.0	16.4	28.0
10	Male	25	Neu	4.8	12.0	23.0	25	Female	4.1	8.7	19.1
10	Male	50	Ext	51.0	15.6	38.2	25	Female	15.8	12.3	23.3
10	Male	50	Flx	7.2	23.4	43.8	25	Female	2.0	17.0	34.0
10	Male	50	Neu	7.2	17.5	34.8	25	Female	6.6	8.8	21.7
10	Male	75	Ext	66.0	20.3	51.0	25	Female	21.9	17.4	28.7
10	Male	75	Flx	10.3	27.5	56.1	25	Female	4.1	26.1	47.3
10	Male	75	Neu	27.9	25.3	53.5	25	Female	9.4	14.1	30.8
11	Male	25	Ext	29.8	24.6	9.4	26	Female	15.0	41.8	15.0
11	Male	25	Flx	4.2	27.5	17.0	26	Female	10.5	74.3	34.9
11	Male	25	Neu	4.6	21.6	11.8	26	Female	8.9	60.2	23.2
11	Male	50	Ext	37.8	27.6	12.9	26	Female	28.3	80.1	32.9
11	Male	50	Flx	13.0	32.3	22.0	26	Female	14.2	81.9	41.4
11	Male	50	Neu	5.3	23.3	17.8	26	Female	14.5	66.7	30.1
11	Male	75	Ext	35.4	35.5	17.0	26	Female	33.4	69.0	33.7
11	Male	75	Flx	12.1	54.6	43.1	26	Female	22.3	92.2	46.4
11	Male	75	Neu	7.5	42.7	31.1	26	Female	29.7	95.4	48.3
12	Male	25	Ext	7.9	14.3	12.7	27	Female	23.2	20.8	17.6
12	Male	25	Flx	2.8	16.6	18.8	27	Female	2.2	26.0	20.1
12	Male	25	Neu	3.5	12.0	12.1	27	Female	1.8	19.5	14.7
12	Male	50	Ext	15.7	22.3	19.8	27	Female	26.3	34.4	30.4
12	Male	50	Flx	4.7	29.0	31.8	27	Female	3.4	39.3	30.5
12	Male	50	Neu	5.5	20.3	21.7	27	Female	2.4	28.7	21.1
12	Male	75	Ext	19.3	36.8	34.8	27	Female	31.0	36.6	33.3
12	Male	75	Flx	17.7	42.5	65.0	27	Female	5.5	59.5	44.9

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
12	Male	75	Neu	8.4	31.8	43.0	27	Female	5.5	39.0	32.2
13	Male	25	Ext	51.6	12.6	21.6	28	Female	22.9	15.3	10.2
13	Male	25	Flx	2.8	40.6	26.1	28	Female	3.4	24.2	17.6
13	Male	25	Neu	5.9	33.5	33.2	28	Female	5.5	21.8	9.3
13	Male	50	Ext	37.5	43.3	32.2	28	Female	48.9	26.0	14.1
13	Male	50	Flx	5.0	63.3	46.8	28	Female	6.9	38.1	24.2
13	Male	50	Neu	10.2	55.4	41.2	28	Female	9.2	33.2	14.3
13	Male	75	Ext	49.9	43.5	36.4	28	Female	66.6	45.5	18.2
13	Male	75	Flx	9.6	75.7	56.0	28	Female	10.0	84.1	39.8
13	Male	75	Neu	9.5	68.3	45.9	28	Female	10.4	46.2	17.0
14	Male	25	Ext	2.4	13.2	7.3	29	Female	24.6	25.9	35.6
14	Male	25	Flx	1.2	18.5	8.7	29	Female	1.8	39.4	22.5
14	Male	25	Neu	1.5	15.8	9.4	29	Female	1.2	44.3	30.5
14	Male	50	Ext	7.7	26.8	20.6	29	Female	39.5	38.3	34.0
14	Male	50	Flx	2.2	33.5	18.9	29	Female	2.8	58.5	48.2
14	Male	50	Neu	2.3	29.4	19.6	29	Female	4.9	49.3	39.3
14	Male	75	Ext	5.9	32.1	25.7	29	Female	44.1	63.4	58.8
14	Male	75	Flx	5.1	45.4	33.7	29	Female	13.7	90.7	98.7
14	Male	75	Neu	3.8	30.5	18.0	29	Female	17.6	78.5	86.4
15	Male	25	Ext	11.1	5.6	11.7	30	Female	13.5	23.9	10.1
15	Male	25	Flx	3.6	5.3	7.2	30	Female	3.2	25.3	23.8
15	Male	25	Neu	3.5	5.3	10.3	30	Female	5.4	18.4	8.1
15	Male	50	Ext	13.3	8.8	18.7	30	Female	39.7	22.7	12.6
15	Male	50	Flx	5.4	10.9	11.3	30	Female	6.7	52.7	30.3
15	Male	50	Neu	6.1	8.5	19.0	30	Female	9.0	33.6	15.0
15	Male	75	Ext	18.5	10.9	20.9	30	Female	47.5	47.6	17.0
15	Male	75	Flx	10.2	8.2	13.1	30	Female	11.3	98.9	44.4
15	Male	75	Neu	7.0	11.8	24.6	30	Female	14.6	55.3	21.7

Task 4: Lifting at knuckle and shoulder heights (using force platform)

Participant no.	Gender	Wt	Lifting_ht	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
1	Male	25	Knuckle	2.5	7.4	4.5	16	Female	8.4	4.2	4.7
1	Male	50	Knuckle	3.0	11.9	6.9	16	Female	11.1	17.5	9.6
1	Male	75	Knuckle	3.5	18.0	11.6	16	Female	9.9	23.7	12.2
1	Male	25	Shoulder	4.7	33.8	24.0	16	Female	12.3	28.0	18.3
1	Male	50	Shoulder	6.2	50.8	33.9	16	Female	10.4	40.1	20.3
1	Male	75	Shoulder	8.7	61.4	54.7	16	Female	21.8	64.4	37.0
2	Male	25	Knuckle	1.1	5.0	7.4	17	Female	6.6	12.0	9.6
2	Male	50	Knuckle	1.1	5.9	7.6	17	Female	6.9	25.9	10.9
2	Male	75	Knuckle	1.4	10.2	12.4	17	Female	7.5	37.2	13.6
2	Male	25	Shoulder	1.2	10.1	10.8	17	Female	9.2	41.8	16.7
2	Male	50	Shoulder	2.0	13.6	14.7	17	Female	12.5	44.3	16.7
2	Male	75	Shoulder	4.3	18.4	25.9	17	Female	20.6	75.0	26.5
3	Male	25	Knuckle	1.2	5.7	12.2	18	Female	6.6	5.5	15.2
3	Male	50	Knuckle	1.4	9.1	11.8	18	Female	7.2	6.1	16.1
3	Male	75	Knuckle	1.5	16.9	12.4	18	Female	9.3	8.4	17.7
3	Male	25	Shoulder	1.7	27.5	20.5	18	Female	12.0	17.3	27.0
3	Male	50	Shoulder	2.3	37.3	25.9	18	Female	15.8	29.6	42.5
3	Male	75	Shoulder	4.1	49.7	38.1	18	Female	21.0	27.2	43.5
4	Male	25	Knuckle	2.5	9.9	12.9	19	Female	1.2	9.5	9.6
4	Male	50	Knuckle	2.3	13.8	15.4	19	Female	1.1	13.4	6.3
4	Male	75	Knuckle	2.5	18.3	19.0	19	Female	1.4	21.3	13.2
4	Male	25	Shoulder	4.0	28.9	29.0	19	Female	1.8	23.8	27.3
4	Male	50	Shoulder	4.2	38.0	36.2	19	Female	2.2	26.4	30.4
4	Male	75	Shoulder	4.9	57.9	50.3	19	Female	4.2	36.7	40.3
5	Male	25	Knuckle	2.6	4.3	6.6	20	Female	17.3	14.1	2.7
5	Male	50	Knuckle	2.6	8.3	9.3	20	Female	15.8	14.0	2.6
5	Male	75	Knuckle	2.7	15.1	13.4	20	Female	19.7	18.5	3.6
5	Male	25	Shoulder	2.5	13.6	13.8	20	Female	20.2	38.3	7.1

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
5	Male	50	Shoulder	3.6	42.6	36.5	20	Female	24.2	41.5	7.4
5	Male	75	Shoulder	6.1	53.7	49.4	20	Female	42.4	51.4	9.3
6	Male	25	Knuckle	2.9	2.1	16.1	21	Female	5.9	2.3	7.7
6	Male	50	Knuckle	2.8	3.1	17.1	21	Female	7.9	4.7	11.3
6	Male	75	Knuckle	3.1	5.1	15.8	21	Female	6.1	6.8	14.0
6	Male	25	Shoulder	5.5	27.0	17.1	21	Female	10.7	17.5	29.0
6	Male	50	Shoulder	8.4	31.3	25.9	21	Female	15.2	23.7	33.2
6	Male	75	Shoulder	14.5	47.7	35.1	21	Female	20.7	34.8	44.9
7	Male	25	Knuckle	4.5	9.9	9.5	22	Female	4.2	3.3	5.0
7	Male	50	Knuckle	3.0	9.7	8.9	22	Female	5.8	5.5	6.5
7	Male	75	Knuckle	6.0	18.5	21.5	22	Female	6.3	7.8	6.2
7	Male	25	Shoulder	5.8	15.7	19.1	22	Female	26.2	33.8	22.3
7	Male	50	Shoulder	17.0	30.0	34.6	22	Female	38.3	45.2	26.3
7	Male	75	Shoulder	13.4	35.7	35.8	22	Female	58.2	53.4	30.2
8	Male	25	Knuckle	1.2	15.2	7.5	23	Female	2.8	4.8	6.2
8	Male	50	Knuckle	1.4	19.1	9.0	23	Female	3.9	6.6	6.7
8	Male	75	Knuckle	1.7	29.0	11.5	23	Female	4.3	8.5	7.6
8	Male	25	Shoulder	1.5	36.6	15.5	23	Female	3.9	23.7	15.2
8	Male	50	Shoulder	1.8	46.5	18.0	23	Female	7.0	28.4	18.3
8	Male	75	Shoulder	3.3	63.3	34.8	23	Female	10.9	51.5	35.9
9	Male	25	Knuckle	3.1	8.9	15.8	24	Female	1.9	4.0	7.1
9	Male	50	Knuckle	3.2	17.8	16.8	24	Female	1.6	9.8	7.8
9	Male	75	Knuckle	3.2	14.8	16.4	24	Female	2.6	9.5	11.0
9	Male	25	Shoulder	4.1	34.6	19.6	24	Female	2.8	18.9	19.6
9	Male	50	Shoulder	3.7	35.2	23.2	24	Female	6.9	26.6	27.9
9	Male	75	Shoulder	3.9	33.4	21.2	24	Female	19.7	37.0	43.5
10	Male	25	Knuckle	5.1	7.8	21.0	25	Female	0.9	1.5	5.3
10	Male	50	Knuckle	4.9	10.1	24.8	25	Female	0.9	2.1	6.3
10	Male	75	Knuckle	13.9	15.7	44.2	25	Female	1.3	3.1	7.4
10	Male	25	Shoulder	8.4	10.7	22.3	25	Female	5.2	12.0	26.8

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
10	Male	50	Shoulder	11.0	15.8	34.7	25	Female	8.4	17.3	32.8
10	Male	75	Shoulder	29.2	25.1	62.7	25	Female	11.8	18.5	37.2
11	Male	25	Knuckle	3.3	2.2	9.6	26	Female	6.3	21.8	11.4
11	Male	50	Knuckle	3.5	2.3	7.5	26	Female	8.5	23.2	13.6
11	Male	75	Knuckle	3.8	2.4	7.5	26	Female	10.1	34.8	16.4
11	Male	25	Shoulder	4.5	29.7	15.6	26	Female	14.5	52.7	18.8
11	Male	50	Shoulder	9.4	28.5	17.2	26	Female	18.5	60.5	24.9
11	Male	75	Shoulder	15.1	42.8	35.5	26	Female	23.7	81.7	35.1
12	Male	25	Knuckle	1.1	5.4	8.1	27	Female	1.9	8.4	8.1
12	Male	50	Knuckle	1.1	6.3	8.6	27	Female	1.8	6.6	7.6
12	Male	75	Knuckle	1.1	10.0	10.6	27	Female	1.9	5.1	7.7
12	Male	25	Shoulder	1.1	10.2	10.1	27	Female	2.7	25.0	14.9
12	Male	50	Shoulder	1.8	14.1	15.1	27	Female	6.5	39.5	34.1
12	Male	75	Shoulder	3.1	20.3	24.1	27	Female	9.5	71.5	56.7
13	Male	25	Knuckle	2.1	12.6	13.6	28	Female	8.2	16.5	8.3
13	Male	50	Knuckle	2.2	15.4	14.5	28	Female	8.0	21.4	9.9
13	Male	75	Knuckle	2.1	22.9	15.5	28	Female	8.7	27.6	12.3
13	Male	25	Shoulder	2.2	26.5	22.7	28	Female	12.0	36.8	15.2
13	Male	50	Shoulder	2.3	31.9	25.3	28	Female	39.2	46.3	20.5
13	Male	75	Shoulder	2.5	35.6	27.3	28	Female	48.7	66.5	30.2
14	Male	25	Knuckle	2.2	7.7	6.8	29	Female	2.9	6.4	7.1
14	Male	50	Knuckle	1.8	12.4	6.4	29	Female	2.8	16.4	9.3
14	Male	75	Knuckle	3.4	15.6	12.2	29	Female	2.8	21.4	10.4
14	Male	25	Shoulder	3.0	18.3	9.7	29	Female	3.3	21.8	14.2
14	Male	50	Shoulder	3.2	28.3	20.2	29	Female	4.0	29.3	19.0
14	Male	75	Shoulder	4.6	37.5	24.2	29	Female	11.4	38.9	28.4
15	Male	25	Knuckle	5.3	1.7	5.6	30	Female	1.0	8.6	9.4
15	Male	50	Knuckle	6.6	2.9	9.2	30	Female	1.0	12.6	7.9
15	Male	75	Knuckle	7.7	4.0	13.8	30	Female	1.4	17.5	12.5
15	Male	25	Shoulder	14.9	7.9	21.5	30	Female	1.5	19.0	20.7

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
15	Male	50	Shoulder	24.5	14.5	27.8	30	Female	2.8	24.8	28.3
15	Male	75	Shoulder	36.6	15.4	33.3	30	Female	5.9	40.5	43.3

Task 5: Pushing and pulling at shoulder height (using force platform)

Participant no.	Gender	Wt	FD	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
1	Male	25	Pull	2.8	3.5	3.6	16	Female	10.3	13.5	8.6
1	Male	50	Pull	2.7	2.2	3.3	16	Female	17.1	11.8	9.1
1	Male	75	Pull	3.0	3.2	3.5	16	Female	18.7	11.6	10.6
1	Male	25	Push	2.7	1.1	3.4	16	Female	6.0	3.9	5.5
1	Male	50	Push	2.5	1.3	3.3	16	Female	16.4	7.8	5.4
1	Male	75	Push	2.8	1.7	3.7	16	Female	15.2	9.4	5.2
2	Male	25	Pull	8.0	1.4	5.3	17	Female	9.5	9.2	8.8
2	Male	50	Pull	8.7	2.2	7.4	17	Female	7.6	13.2	9.4
2	Male	75	Pull	16.4	3.6	10.3	17	Female	8.2	6.3	8.6
2	Male	25	Push	8.0	0.9	3.7	17	Female	9.9	4.0	7.9
2	Male	50	Push	10.4	0.9	3.0	17	Female	9.7	4.3	7.9
2	Male	75	Push	10.2	1.2	3.5	17	Female	8.7	4.2	7.8
3	Male	25	Pull	1.6	14.9	12.2	18	Female	6.6	3.4	14.5
3	Male	50	Pull	1.8	4.2	8.3	18	Female	5.4	3.4	14.5
3	Male	75	Pull	1.3	8.3	10.0	18	Female	6.1	5.4	14.9
3	Male	25	Push	1.5	5.5	8.7	18	Female	6.9	2.1	14.3
3	Male	50	Push	1.4	3.6	8.8	18	Female	6.7	2.0	13.7
3	Male	75	Push	1.9	2.3	18.1	18	Female	6.7	2.3	14.0
4	Male	25	Pull	2.6	19.8	18.4	19	Female	1.4	0.8	3.3
4	Male	50	Pull	2.9	19.8	17.3	19	Female	1.3	1.4	3.5

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
4	Male	75	Pull	2.9	15.3	16.5	19	Female	1.7	1.0	3.6
4	Male	25	Push	3.0	9.1	14.5	19	Female	2.0	2.0	3.8
4	Male	50	Push	3.0	3.4	13.0	19	Female	1.8	2.6	4.2
4	Male	75	Push	2.7	4.7	13.4	19	Female	1.5	2.4	5.0
5	Male	25	Pull	2.2	4.9	6.5	20	Female	18.2	22.7	4.0
5	Male	50	Pull	2.2	6.0	6.0	20	Female	19.6	28.0	4.5
5	Male	75	Pull	2.2	6.2	5.8	20	Female	20.4	31.5	5.0
5	Male	25	Push	2.3	2.8	4.9	20	Female	17.2	9.5	2.2
5	Male	50	Push	2.2	2.3	4.9	20	Female	17.1	10.0	2.1
5	Male	75	Push	2.2	2.8	5.4	20	Female	18.9	12.0	2.2
6	Male	25	Pull	2.7	12.5	17.5	21	Female	3.5	5.8	10.9
6	Male	50	Pull	2.7	11.0	16.4	21	Female	6.2	7.5	12.1
6	Male	75	Pull	2.7	13.1	18.1	21	Female	4.8	9.1	12.4
6	Male	25	Push	2.7	4.0	18.0	21	Female	3.1	1.3	5.1
6	Male	50	Push	2.7	10.1	18.1	21	Female	2.5	0.8	5.6
6	Male	75	Push	2.9	8.9	16.9	21	Female	2.7	0.9	8.2
7	Male	25	Pull	6.2	3.5	5.2	22	Female	5.8	1.7	3.1
7	Male	50	Pull	5.9	6.2	5.5	22	Female	9.0	8.5	6.2
7	Male	75	Pull	5.6	4.6	5.4	22	Female	19.3	22.0	11.4
7	Male	25	Push	3.5	1.2	5.3	22	Female	5.5	2.3	3.7
7	Male	50	Push	3.9	1.4	5.9	22	Female	7.5	2.7	4.7
7	Male	75	Push	3.6	1.6	5.5	22	Female	24.2	3.0	8.8
8	Male	25	Pull	1.3	23.8	10.2	23	Female	2.9	7.2	5.6
8	Male	50	Pull	1.4	35.3	13.5	23	Female	5.1	6.4	5.7
8	Male	75	Pull	1.5	30.9	11.5	23	Female	4.7	11.8	6.1
8	Male	25	Push	1.2	4.4	6.7	23	Female	4.1	3.7	4.8
8	Male	50	Push	1.1	1.9	6.1	23	Female	3.2	3.4	5.3
8	Male	75	Push	1.2	2.8	6.2	23	Female	4.7	5.1	5.4
9	Male	25	Pull	3.1	6.3	14.4	24	Female	1.8	10.3	7.8
9	Male	50	Pull	3.5	5.9	15.1	24	Female	1.0	0.8	3.8

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
9	Male	75	Pull	3.3	9.7	15.3	24	Female	3.6	17.0	14.4
9	Male	25	Push	3.1	1.4	15.3	24	Female	2.1	2.1	6.4
9	Male	50	Push	3.1	1.5	15.5	24	Female	3.5	1.3	6.5
9	Male	75	Push	3.3	1.9	16.3	24	Female	3.7	2.0	8.0
10	Male	25	Pull	4.5	6.4	16.3	25	Female	1.3	0.5	3.2
10	Male	50	Pull	8.1	5.9	17.9	25	Female	1.9	3.2	7.8
10	Male	75	Pull	10.5	11.4	28.8	25	Female	5.5	7.9	14.4
10	Male	25	Push	4.9	3.5	16.0	25	Female	1.2	0.9	3.6
10	Male	50	Push	10.0	1.8	16.1	25	Female	1.2	1.0	3.7
10	Male	75	Push	7.3	2.2	15.7	25	Female	5.2	1.3	10.2
11	Male	25	Pull	8.1	7.2	6.6	26	Female	9.2	9.3	6.1
11	Male	50	Pull	6.3	5.9	6.6	26	Female	9.0	6.5	5.9
11	Male	75	Pull	8.4	6.1	7.0	26	Female	10.3	9.7	6.0
11	Male	25	Push	5.2	2.5	6.7	26	Female	7.9	4.6	5.8
11	Male	50	Push	6.5	3.9	7.4	26	Female	7.6	5.7	5.8
11	Male	75	Push	5.1	4.3	7.7	26	Female	8.3	7.2	6.9
12	Male	25	Pull	3.5	4.7	6.0	27	Female	1.9	2.7	7.1
12	Male	50	Pull	3.8	5.3	6.1	27	Female	2.3	3.2	6.9
12	Male	75	Pull	3.6	4.9	5.9	27	Female	2.4	3.1	7.2
12	Male	25	Push	2.3	1.8	5.0	27	Female	2.1	2.2	7.3
12	Male	50	Push	2.9	1.3	5.3	27	Female	2.6	1.8	7.5
12	Male	75	Push	2.7	1.9	7.0	27	Female	2.3	1.7	7.8
13	Male	25	Pull	2.1	15.9	14.3	28	Female	17.2	12.0	7.3
13	Male	50	Pull	2.1	15.8	13.6	28	Female	26.6	9.9	5.2
13	Male	75	Pull	2.6	14.1	12.7	28	Female	15.2	13.6	5.7
13	Male	25	Push	2.2	6.9	13.4	28	Female	21.2	3.7	5.0
13	Male	50	Push	2.5	5.5	12.0	28	Female	16.6	3.6	5.9
13	Male	75	Push	2.2	4.2	11.9	28	Female	21.9	3.6	5.9
14	Male	25	Pull	1.9	2.8	4.6	29	Female	2.6	6.3	5.6
14	Male	50	Pull	2.8	3.3	5.1	29	Female	2.6	9.8	6.9

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
14	Male	75	Pull	2.5	4.8	5.1	29	Female	2.7	12.7	5.1
14	Male	25	Push	2.3	6.2	4.4	29	Female	2.9	2.2	5.2
14	Male	50	Push	3.2	9.8	4.5	29	Female	3.0	1.7	5.9
14	Male	75	Push	2.9	10.2	4.7	29	Female	3.7	6.7	7.2
15	Male	25	Pull	6.3	1.6	4.6	30	Female	2.6	9.9	6.2
15	Male	50	Pull	9.4	1.8	6.2	30	Female	2.5	11.1	6.8
15	Male	75	Pull	12.7	2.5	12.6	30	Female	2.6	11.2	5.9
15	Male	25	Push	8.0	1.1	3.9	30	Female	2.8	1.8	5.1
15	Male	50	Push	10.4	0.7	3.0	30	Female	3.0	3.1	5.9
15	Male	75	Push	10.2	0.9	3.1	30	Female	3.5	1.8	6.4

Task 6: Overhead pulling (using force platform)

Participant no.	Gender	Wt	FD	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
1	Male	25	Pull	2.8	1.4	3.6	16	Female	9.6	2.3	4.4
1	Male	50	Pull	3.5	1.2	3.9	16	Female	8.2	0.9	3.0
1	Male	75	Pull	3.9	3.1	4.0	16	Female	10.6	1.2	3.3
2	Male	25	Pull	5.2	0.2	2.7	17	Female	9.3	5.1	8.8
2	Male	50	Pull	6.0	0.3	3.0	17	Female	8.6	2.7	7.9
2	Male	75	Pull	9.3	0.3	3.1	17	Female	7.6	2.1	8.0
3	Male	25	Pull	3.2	1.8	8.6	18	Female	5.4	2.1	13.3
3	Male	50	Pull	3.3	4.9	9.1	18	Female	7.6	1.8	14.9
3	Male	75	Pull	3.2	9.9	9.6	18	Female	6.4	2.1	14.1
4	Male	25	Pull	2.4	5.3	12.5	19	Female	0.9	1.0	4.4
4	Male	50	Pull	3.2	9.3	15.1	19	Female	1.0	0.9	3.9
4	Male	75	Pull	2.4	12.8	15.1	19	Female	1.1	1.1	4.3
5	Male	25	Pull	2.3	4.5	8.4	20	Female	18.0	7.9	2.1
5	Male	50	Pull	2.3	1.5	5.1	20	Female	18.0	6.8	2.1

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
5	Male	75	Pull	2.4	2.0	5.8	20	Female	18.3	7.1	2.2
6	Male	25	Pull	4.0	1.8	11.9	21	Female	9.1	1.5	5.9
6	Male	50	Pull	4.9	3.2	11.7	21	Female	9.0	0.6	4.6
6	Male	75	Pull	7.7	15.1	13.0	21	Female	19.2	0.8	6.1
7	Male	25	Pull	3.8	1.9	5.3	22	Female	6.6	1.3	3.2
7	Male	50	Pull	4.5	0.7	6.0	22	Female	6.8	3.3	4.3
7	Male	75	Pull	4.0	0.7	5.2	22	Female	23.9	1.8	7.8
8	Male	25	Pull	1.8	1.0	5.9	23	Female	3.6	3.5	5.5
8	Male	50	Pull	1.5	1.0	5.5	23	Female	2.3	3.4	5.6
8	Male	75	Pull	1.6	1.1	5.6	23	Female	3.6	2.8	5.9
9	Male	25	Pull	3.2	1.9	13.9	24	Female	1.6	0.5	4.3
9	Male	50	Pull	3.1	1.8	14.2	24	Female	2.3	1.0	4.5
9	Male	75	Pull	3.3	2.1	14.1	24	Female	2.8	1.0	4.5
10	Male	25	Pull	7.2	1.6	14.4	25	Female	1.1	0.5	3.6
10	Male	50	Pull	16.4	1.3	15.0	25	Female	1.2	0.7	5.1
10	Male	75	Pull	14.1	1.5	18.2	25	Female	3.5	1.8	4.2
11	Male	25	Pull	2.8	6.4	6.9	26	Female	9.6	7.0	7.1
11	Male	50	Pull	2.9	3.9	7.5	26	Female	12.6	12.3	9.9
11	Male	75	Pull	3.1	2.0	6.9	26	Female	12.5	9.7	9.1
12	Male	25	Pull	2.9	0.4	5.5	27	Female	3.4	2.1	7.7
12	Male	50	Pull	3.1	0.7	5.5	27	Female	2.4	1.1	7.3
12	Male	75	Pull	2.9	3.7	5.8	27	Female	2.6	1.1	7.7
13	Male	25	Pull	2.0	3.3	13.8	28	Female	20.8	3.3	3.9
13	Male	50	Pull	2.0	4.8	13.7	28	Female	10.1	2.5	4.3
13	Male	75	Pull	2.1	13.5	14.7	28	Female	18.9	2.4	4.6
14	Male	25	Pull	1.4	4.1	7.3	29	Female	2.6	0.7	4.1
14	Male	50	Pull	2.1	3.5	9.3	29	Female	2.6	0.9	5.5
14	Male	75	Pull	3.6	1.4	7.2	29	Female	3.0	1.3	4.4
15	Male	25	Pull	5.2	0.2	2.7	30	Female	2.5	0.9	4.7

Participant no.	Gender	Wt	Neck	SCM	TRP_C7	TRP_C4	Participant no.	Gender	SCM	TRP_C7	TRP_C4
15	Male	50	Pull	5.5	0.2	3.1	30	Female	2.8	1.2	4.6
15	Male	75	Pull	7.0	0.3	3.2	30	Female	3.3	1.6	5.3

APPENDIX G: STATISTICS RESULTS

Task 1: Lifting at elbow height

Dependent variable	Within subject variables	
1) SCM=Sternocleidomastoid N-MAV 2) TRP_C4 = upper trapezius (alnong C4) N-MAV 3) TRP_C7 = upper trapezius (alnong C7) N-MAV	Neck postures (3 levels) 1) 1= extension 2) 2 = flexion 3) 3= neutral	Weights (3 levels) 1) 25% 2) 50% 3) 75%

Analysis of Variance Table for SCM

Source	DF	SS	MS	F	P
Sub	29	17812.3	614.22		
Neck	2	10496.3	5248.14	18.56	0.00000
Error	Sub*Neck	58	16399.8	282.76	
Wt	2	1011.9	505.96	30.83	0.00000
Error	Sub*Wt	58	951.8	16.41	
Neck*Wt	4	361.3	90.34	10.66	0.00000
Error	Sub*Neck*Wt	116	983.2	8.48	
Total	269	48016.6			
Grand Mean		8.8839			
	CV(Sub*Neck)	189.28			
	CV(Sub*Wt)	45.6			
	CV(Sub*Neck*Wt)	32.77			

Analysis of Variance Table for TRP_C4

Source	DF	SS	MS	F	P
Sub	29	7101.7	244.89		
Neck	2	1175.8	587.88	18.01	0.00000
Error	Sub*Neck	58	1893.3	32.64	
Wt	2	5672.1	2836.03	88.82	0.00000
Error	Sub*Wt	58	1852	31.93	
Neck*Wt	4	47.8	11.94	0.61	0.65900
Error	Sub*Neck*Wt	116	2285.4	19.7	
Total	269	20027.9			
Grand Mean		16.975			
	CV(Sub*Neck)	33.66			
	CV(Sub*Wt)	33.29			
	CV(Sub*Neck*Wt)	26.15			

Analysis of Variance Table for TRP C7

Source	DF	SS	MS	F	P
Sub	29	25962	895.24		
Neck	2	1916.3	958.14	17.98	0.00000
Error	Sub*Neck	58	3090.9	53.29	
Wt	2	10144	5072.01	75.13	0.00000
Error	Sub*Wt	58	3915.4	67.51	
Neck*Wt	4	142.5	35.62	1.65	0.16600
Error	Sub*Neck*Wt	116	2501.4	21.56	
Total	269	47672.5			
Grand Mean		20.137			
	CV(Sub*Neck)	36.25			
	CV(Sub*Wt)	40.8			
	CV(Sub*Neck*Wt)	23.06			

Tukey HSD All-Pairwise Comparisons Test of SCM for Neck*Wt

Neck	Wt	Mean	1,25	1,50	1,75	2,25	2,50	2,75	3,25
1	25	13.446							
1	50	17.515	4.069*						
1	75	22.143	8.697*	4.628*					
2	25	3.461	9.985*	14.054*	18.682*				
2	50	4.023	9.423*	13.492*	18.120*	0.562			
2	75	5.885	7.561	11.630*	16.258*	2.424	1.862		
3	25	3.14	10.306*	14.375*	19.003*	0.321	0.883	2.745	
3	50	4.188	9.258*	13.328*	17.955*	0.727	0.165	1.697	1.048
3	75	6.154	7.292	11.361*	15.989*	2.694	2.131	0.269	3.014*
Neck	Wt	Mean	3,50						
3	50	4.188							
3	75	6.154	1.967						

Comparisons of means for the same level of Neck
Alpha 0.05 Standard Error for Comparison 0.8610
Critical Q Value 4.511 Critical Value for Comparison 2.7467
Error terms used: Sub*Wt and Sub*Neck*Wt
Comparisons of means for different levels of Neck
Alpha 0.05 Standard Error for Comparison 2.5807
Critical Q Value 4.550 Critical Value for Comparison 8.3032
Error terms used: Sub*Neck and Sub*Neck*Wt

Tukey HSD All-Pairwise Comparisons Test of TRP C4 for Neck*Wt

Neck	Wt	Mean	1,25	1,50	1,75	2,25	2,50	2,75	3,25
1	25	9.53							
1	50	14.868	5.338*						
1	75	20.893	11.364*	6.025*					
2	25	14.404	4.875*	0.463	6.489*				
2	50	18.848	9.318*	3.98	2.045	4.444*			
2	75	26.404	16.875*	11.537*	5.511*	12.000*	7.556*		
3	25	10.866	1.336	4.002	10.027*	3.539	7.982*	15.539*	
3	50	15.861	6.332*	0.994	5.032*	1.457	2.987	10.543*	4.996*
3	75	21.102	11.573*	6.234*	0.209	6.698*	2.254	5.302*	10.237*
Neck	Wt	Mean	3,50						
3	50	15.861							
3	75	21.102	5.241*						

Comparisons of means for the same level of Neck
Alpha 0.05 Standard Error for Comparison 1.2590
Critical Q Value 4.508 Critical Value for Comparison 4.0130
Error terms used: Sub*Wt and Sub*Neck*Wt
Comparisons of means for different levels of Neck
Alpha 0.05 Standard Error for Comparison 1.2653
Critical Q Value 4.508 Critical Value for Comparison 4.0334
Error terms used: Sub*Neck and Sub*Neck*Wt

Tukey HSD All-Pairwise Comparisons Test of TRP C7 for Neck*Wt

Neck	Wt	Mean	1,25	1,50	1,75	2,25	2,50	2,75	3,25
1	25	10.427							
1	50	18.281	7.854*						
1	75	24.615	14.188*	6.334*					
2	25	15.797	5.370*	2.484	8.819*				
2	50	23.053	12.626*	4.772*	1.562	7.256*			
2	75	32.731	22.303*	14.449*	8.115*	16.934*	9.678*		
3	25	11.486	1.059	6.795*	13.130*	4.311	11.567*	21.245*	
3	50	19.445	9.018*	1.164	5.171*	3.648	3.608	13.286*	7.959*
3	75	25.401	14.974*	7.120*	0.786	9.604*	2.348	7.329*	13.916*
Neck	Wt	Mean	3,50						
3	50	19.445							
3	75	25.401	5.957*						

Comparisons of means for the same level of Neck
Alpha 0.05 Standard Error for Comparison 1.5680
Critical Q Value 4.521 Critical Value for Comparison 5.0131
Error terms used: Sub*Wt and Sub*Neck*Wt
Comparisons of means for different levels of Neck
Alpha 0.05 Standard Error for Comparison 1.4638
Critical Q Value 4.517 Critical Value for Comparison 4.6748
Error terms used: Sub*Neck and Sub*Neck*Wt

Task 2: Lifting at shoulder height

Dependent variable	**Within subject variables**	
1) SCM=Sternocleidomastoid N-MAV 2) TRP_C4 = upper trapezius (alnong C4) N-MAV 3) TRP_C7 = upper trapezius (alnong C7) N-MAV	Neck postures (3 levels) 1) 1= extension 2) 2 = flexion 3) 3= neutral	Weights (3 levels) 1) 25% 2) 50% 3) 75%

Analysis of Variance Table for SCM

Source	DF	SS	MS	F	P
Sub	29	21566.4	743.67		
Neck	2	19182.6	9591.3	37.19	0.00000
Error	Sub*Neck	58	14956.8	257.88	
Wt	2	2558.2	1279.11	31.55	0.00000
Error	Sub*Wt	58	2351.7	40.55	
Neck*Wt	4	218.4	54.61	2.9	0.02480
Error	Sub*Neck*Wt	116	2182.7	18.82	
Total	269	63016.8			
Grand Mean		13.251			
	CV(Sub*Neck)	121.19			
	CV(Sub*Wt)	48.05			
	CV(Sub*Neck*Wt)	32.74			

Analysis of Variance Table for TRPU_C4

Source	DF	SS	MS	F	P
Sub	29	57994	1999.81		
Neck	2	7576	3788.18	37.47	0.00000
Error	Sub*Neck	58	5864	101.1	
Wt	2	18823	9411.28	41.98	0.00000
Error	Sub*Wt	58	13002	224.17	
Neck*Wt	4	1053	263.29	8.12	0.00000
Error	Sub*Neck*Wt	116	3762	32.43	
Total	269	108074			
Grand Mean		29.382			
	CV(Sub*Neck)	34.22			
	CV(Sub*Wt)	50.96			
	CV(Sub*Neck*Wt)	19.38			

Analysis of Variance Table for TRP C7

Source	DF	SS	MS	F	P
Sub	29	122790	4234.1		
Neck	2	5043	2521.4	28.08	0.00000
Error	Sub*Neck	58	5208	89.8	
Wt	2	23828	11914.1	36.88	0.00000
Error	Sub*Wt	58	18737	323	
Neck*Wt	4	749	187.2	4	0.00440
Error	Sub*Neck*Wt	116	5425	46.8	
Total	269	181780			
Grand Mean		37.359			
	CV(Sub*Neck)	25.36			
	CV(Sub*Wt)	48.11			
	CV(Sub*Neck*Wt)	18.31			

Tukey HSD All-Pairwise Comparisons Test of SCM for Neck*Wt

Neck	Wt	Mean	1,25	1,50	1,75	2,25	2,50	2,75	3,25
1	25	20.36							
1	50	24.298	3.938						
1	75	30.837	10.477*	6.539*					
2	25	4.648	15.712*	19.650*	26.189*				
2	50	7.165	13.195*	17.133*	23.672*	2.517			
2	75	11.045	9.315*	13.254*	19.793*	6.397*	3.88		
3	25	4.201	16.159*	20.097*	26.636*	0.447	2.964	6.843	
3	50	6.887	13.473*	17.411*	23.950*	2.239	0.278	4.158	2.686
3	75	9.816	10.544*	14.482*	21.021*	5.168	2.651	1.228	5.615*
Neck	Wt	Mean	3,50						
3	50	6.887							
3	75	9.816	2.929						

Comparisons of means for the same level of Neck
Alpha 0.05 Standard Error for Comparison 1.3181
Critical Q Value 4.514 Critical Value for Comparison 4.2068
Error terms used: Sub*Wt and Sub*Neck*Wt
Comparisons of means for different levels of Neck
Alpha 0.05 Standard Error for Comparison 2.5626
Critical Q Value 4.544 Critical Value for Comparison 8.2339
Error terms used: Sub*Neck and Sub*Neck*Wt

Tukey HSD All-Pairwise Comparisons Test of TRPU C4 for Neck*Wt

Neck	Wt	Mean	1,25	1,50	1,75	2,25	2,50	2,75	3,25
1	25	16.48							
1	50	23.723	7.243						
1	75	32.71	16.231*	8.987*					
2	25	23.755	7.276*	0.033	8.955*				
2	50	35.55	19.071*	11.827*	2.84	11.795*			
2	75	50.768	34.288*	27.045*	18.058*	27.012*	15.218*		
3	25	17.914	1.434	5.809	14.796*	5.842	17.636*	32.854*	
3	50	27.557	11.078*	3.835	5.153	3.802	7.993*	23.210*	9.644*
3	75	35.984	19.504*	12.261*	3.274	12.229*	0.434	14.784*	18.070*
Neck	Wt	Mean	3,50						
3	50	27.557							
3	75	35.984	8.426*						

Comparisons of means for the same level of Neck
Alpha 0.05 Standard Error for Comparison 2.5343
Critical Q Value 4.536 Critical Value for Comparison 8.1282
Error terms used: Sub*Wt and Sub*Neck*Wt
Comparisons of means for different levels of Neck
Alpha 0.05 Standard Error for Comparison 1.9204
Critical Q Value 4.521 Critical Value for Comparison 6.1398
Error terms used: Sub*Neck and Sub*Neck*Wt

Tukey HSD All-Pairwise Comparisons Test of TRP C7 for Neck*Wt

Neck	Wt	Mean	1,25	1,50	1,75	2,25	2,50	2,75	3,25
1	25	23.59							
1	50	32.809	9.218						
1	75	44.799	21.209*	11.991*					
2	25	29.422	5.832	3.386	15.377*				
2	50	43.242	19.652*	10.433*	1.557	13.820*			
2	75	57.635	34.045*	24.826*	12.836*	28.213*	14.393*		
3	25	24.433	0.843	8.375*	20.366*	4.989	18.809*	33.202*	
3	50	36.26	12.670*	3.451	8.539*	6.838*	6.982*	21.375*	11.827*
3	75	44.044	20.454*	11.235*	0.755	14.622*	0.802	13.591*	19.611*
Neck	Wt	Mean	3,50						
3	50	36.26							
3	75	44.044	7.784						

Comparisons of means for the same level of Neck
Alpha 0.05 Standard Error for Comparison 3.0426
Critical Q Value 4.536 Critical Value for Comparison 9.7583
Error terms used: Sub*Wt and Sub*Neck*Wt
Comparisons of means for different levels of Neck
Alpha 0.05 Standard Error for Comparison 2.0184
Critical Q Value 4.511 Critical Value for Comparison 6.4384
Error terms used: Sub*Neck and Sub*Neck*Wt

Task 3: Lifting at Overhead height

Dependent variable	**Within subject variables**	
1) SCM=Sternocleidomastoid N-MAV 2) TRP_C4 = upper trapezius (alnong C4) N-MAV 3) TRP_C7 = upper trapezius (alnong C7) N-MAV	Neck postures (3 levels) 1) 1= extension 2) 2 = flexion 3) 3= neutral	Weights (3 levels) 1) 25% 2) 50% 3) 75%

Analysis of Variance Table for SCM

Source	DF	SS	MS	F	P
Sub	29	41221	1421.4		
Neck	2	29925	14962.7	37.38	0.00000
Error	Sub*Neck	58	23220	400.3	
Wt	2	6495	3247.5	53.66	0.00000
Error	Sub*Wt	58	3510	60.5	
Neck*Wt	4	399	99.8	3.72	0.00690
Error	Sub*Neck*Wt	116	3107	26.8	
Total	269	107877			
Grand Mean		18.31			
	CV(Sub*Neck)	109.28			
	CV(Sub*Wt)	42.49			
	CV(Sub*Neck*Wt)	28.26			

Analysis of Variance Table for TRP_C4

Source	DF	SS	MS	F	P
Sub	29	71133	2452.9		
Neck	2	3812	1905.9	22.78	0.00000
Error	Sub*Neck	58	4852	83.6	
Wt	2	29502	14751.1	49.62	0.00000
Error	Sub*Wt	58	17241	297.3	
Neck*Wt	4	779	194.7	1.96	0.10560
Error	Sub*Neck*Wt	116	11536	99.4	
Total	269	138855			
Grand	Mean	31.894			
	CV(Sub*Neck)	28.68			
	CV(Sub*Wt)	54.06			
	CV(Sub*Neck*Wt)	31.27			

Analysis of Variance Table for TRP C7

Source	DF	SS	MS	F	P
Sub	29	89020	3069.7		
Neck	2	5128	2564.2	21.18	0.00000
Error	Sub*Neck	58	7022	121.1	
Wt	2	30316	15158	100.25	0.00000
Error	Sub*Wt	58	8769	151.2	
Neck*Wt	4	240	60	0.64	0.63450
Error	Sub*Neck*Wt	116	10858	93.6	
Total	269	151354			
Grand	Mean	40.268			
	CV(Sub*Neck)	27.32			
	CV(Sub*Wt)	30.54			
	CV(Sub*Neck*Wt)	24.03			

Tukey HSD All-Pairwise Comparisons Test of SCM for Neck*Wt

Neck	Wt	Mean	1,25	1,50	1,75	2,25	2,50	2,75	3,25
1	25	24.906							
1	50	34.232	9.326*						
1	75	40.456	15.550*	6.224*					
2	25	6.386	18.521*	27.846*	34.070*				
2	50	9.684	15.223*	24.548*	30.773*	3.298			
2	75	16.198	8.708	18.034*	24.258*	9.812*	6.514*		
3	25	5.966	18.941*	28.266*	34.490*	0.42	3.718	10.232*	
3	50	10.337	14.569*	23.895*	30.119*	3.951	0.653	5.861	4.371
3	75	16.627	8.28	17.606*	23.830*	10.241*	6.943	0.428	10.661*
Neck	Wt	Mean	3,50						
3	50	10.337							
3	75	16.627	6.290*						

Comparisons of means for the same level of Neck
Alpha 0.05 Standard Error for Comparison 1.5922
Critical Q Value 4.515 Critical Value for Comparison 5.0830
Error terms used: Sub*Wt and Sub*Neck*Wt
Comparisons of means for different levels of Neck
Alpha 0.05 Standard Error for Comparison 3.1760
Critical Q Value 4.545 Critical Value for Comparison 10.207
Error terms used: Sub*Neck and Sub*Neck*Wt

Tukey HSD All-Pairwise Comparisons Test of TRP C4 for Neck*Wt

Neck	Wt	Mean	1,25	1,50	1,75	2,25	2,50	2,75	3,25
1	25	19.092							
1	50	26.998	7.906						
1	75	40.133	21.041*	13.135*					
2	25	22.944	3.852	4.054	17.189*				
2	50	34.899	15.807*	7.901	5.234	11.955*			
2	75	53.682	34.590*	26.684*	13.549*	30.738*	18.783*		
3	25	17.825	1.266	9.172*	22.307*	5.119	17.073*	35.857*	
3	50	29.055	9.963*	2.057	11.078*	6.111	5.844	24.627*	11.230*
3	75	42.422	23.331*	15.425*	2.29	19.478*	7.524	11.260*	24.597*
Neck	Wt	Mean	3,50						
3	50	29.055							
3	75	42.422	13.367*						

Comparisons of means for the same level of Neck
Alpha 0.05 Standard Error for Comparison 3.3205
Critical Q Value 4.521 Critical Value for Comparison 10.614
Error terms used: Sub*Wt and Sub*Neck*Wt
Comparisons of means for different levels of Neck
Alpha 0.05 Standard Error for Comparison 2.5058
Critical Q Value 4.495 Critical Value for Comparison 7.9636
Error terms used: Sub*Neck and Sub*Neck*Wt

Tukey HSD All-Pairwise Comparisons Test of TRP C7 for Neck*Wt

Neck	Wt	Mean	1,25	1,50	1,75	2,25	2,50	2,75	3,25
1	25	25.632							
1	50	36.166	10.534*						
1	75	48.864	23.232*	12.698*					
2	25	32.161	6.529	4.006	16.704*				
2	50	46.314	20.682*	10.148*	2.55	14.153*			
2	75	60.79	35.158*	24.624*	11.926*	28.629*	14.476*		
3	25	25.064	0.569	11.103*	23.801*	7.097	21.251*	35.727*	
3	50	36.423	10.791*	0.257	12.441*	4.262	9.891*	24.367*	11.359*
3	75	50.999	25.367*	14.833*	2.135	18.838*	4.685	9.791*	25.935*
Neck	Wt	Mean	3,50						
3	50	36.423							
3	75	50.999	14.576*						

Comparisons of means for the same level of Neck
Alpha 0.05 Standard Error for Comparison 2.7423
Critical Q Value 4.507 Critical Value for Comparison 8.7404
Error terms used: Sub*Wt and Sub*Neck*Wt
Comparisons of means for different levels of Neck
Alpha 0.05 Standard Error for Comparison 2.6174
Critical Q Value 4.503 Critical Value for Comparison 8.3337
Error terms used: Sub*Neck and Sub*Neck*Wt

<u>Task 4: Lifting at knuckle and shoulder heights (using force platform)</u>

Dependent variable	**Within subject variables**	
1) SCM=Sternocleidomastoid N-MAV 2) TRP_C4 = upper trapezius (alnong C4) N-MAV 3) TRP_C7 = upper trapezius (alnong C7) N-MAV	Lifting heights (2 levels) 1) 1= knuckel 2) 3 = shoulder	Weights (3 levels) 1) 25% 2) 50% 3) 75%

Analysis of Variance Table for SCM

Source	DF	SS	MS	F	P
Sub	29	7173.8	247.37		
Wt	2	845.7	422.83	28.51	0.00000
Error	Sub*Wt	58	860.1	14.83	
Lifting_h	1	2059	2058.96	23.06	0.00000
Error	Sub*Lifting_h	29	2589.4	89.29	
Wt*Lifting_h	2	513.3	256.67	23.1	0.00000
Error	Sub*Wt*Lifting_h	58	644.6	11.11	
Total	179	14685.8			
Grand	Mean	7.7435			
	CV(Sub*Wt)	49.73			
	CV(Sub*Lifting_h)	122.03			
	CV(Sub*Wt*Lifting_h)	43.05			

Analysis of Variance Table for TRP_C4

Source	DF	SS	MS	F	P
Sub	29	4976.2	171.6		
Wt	2	3713	1856.5	82.54	0.00000
Error	Sub*Wt	58	1304.6	22.5	
Lifting_h	1	11622.1	11622.1	160.95	0.00000
Error	Sub*Lifting_h	29	2094.1	72.2	
Wt*Lifting_h	2	1343	671.5	50.85	0.00000
Error	Sub*Wt*Lifting_h	58	765.9	13.2	
Total	179	25818.8			
Grand	Mean	18.972			
	CV(Sub*Wt)	25			
	CV(Sub*Lifting_h)	44.79			
	CV(Sub*Wt*Lifting_h)	19.15			

Analysis of Variance Table for TRP_C7

Source	DF	SS	MS	F	P
Sub	29	13796.6	475.7		
Wt	2	6006.8	3003.4	103.6	0.00000
Error	Sub*Wt	58	1681.5	29	
Lifting_h	1	23115.5	23115.5	162.3	0.00000
Error	Sub*Lifting_h	29	4130.4	142.4	
Wt*Lifting_h	2	1143.8	571.9	30.15	0.00000
Error	Sub*Wt*Lifting_h	58	1100	19	
Total	179	50974.5			
Grand	Mean	22.781			
	CV(Sub*Wt)	23.64			
	CV(Sub*Lifting_h)	52.39			
	CV(Sub*Wt*Lifting_h)	19.12			

Tukey HSD All-Pairwise Comparisons Test of SCM for Wt*Lifting_h

Wt	Lifting_h	Mean	25,1	25,3	50,1	50,3	75,1
25	1	3.891					
25	3	6.785	2.894				
50	1	4.163	0.272	2.622			
50	3	10.438	6.547*	3.653*	6.275*		
75	1	5.03	1.139	1.755	0.867	5.409*	
75	3	16.154	12.262*	9.369*	11.990*	5.715*	11.124*

Comparisons of means for the same level of Wt
  Alpha 0.05 Standard Error for Comparison 1.5742
  Critical Q Value 4.283 Critical Value for Comparison 4.7672
  Error terms used: Sub*Lifting_h and Sub*Wt*Lifting_h
Comparisons of means for different levels of Wt
  Alpha 0.05 Standard Error for Comparison 0.9299
  Critical Q Value 4.168 Critical Value for Comparison 2.7405
  Error terms used: Sub*Wt and Sub*Wt*Lifting_h

Tukey HSD All-Pairwise Comparisons Test of TRP_C4 for Wt*Lifting_h

Wt	Lifting_h	Mean	25,1	25,3	50,1	50,3	75,1
25	1	9.151					
25	3	18.815	9.664*				
50	1	10.195	1.044	8.620*			
50	3	25.73	16.579*	6.915*	15.535*		
75	1	13.463	4.312*	5.352*	3.268*	12.267*	
75	3	36.476	27.326*	17.662*	26.281*	10.746*	23.013*

Comparisons of means for the same level of Wt
Alpha 0.05 Standard Error for Comparison 1.4804
Critical Q Value 4.273 Critical Value for Comparison 4.4728
Error terms used: Sub*Lifting_h and Sub*Wt*Lifting_h
Comparisons of means for different levels of Wt
Alpha 0.05 Standard Error for Comparison 1.0908
Critical Q Value 4.168 Critical Value for Comparison 3.2148
Error terms used: Sub*Wt and Sub*Wt*Lifting_h

Tukey HSD All-Pairwise Comparisons Test of TRP_C7 for Wt*Lifting_h

Wt	Lifting_h	Mean	25,1	25,3	50,1	50,3	75,1
25	1	7.621					
25	3	24.719	17.098*				
50	1	11.133	3.512	13.586*			
50	3	32.723	25.102*	8.004*	21.590*		
75	1	15.59	7.969*	9.129*	4.457*	17.133*	
75	3	44.896	37.275*	20.177*	33.763*	12.173*	29.306*

Comparisons of means for the same level of Wt
Alpha 0.05 Standard Error for Comparison 2.0020
Critical Q Value 4.281 Critical Value for Comparison 6.0604
Error terms used: Sub*Lifting_h and Sub*Wt*Lifting_h
Comparisons of means for different levels of Wt
Alpha 0.05 Standard Error for Comparison 1.2643
Critical Q Value 4.168 Critical Value for Comparison 3.7261
Error terms used: Sub*Wt and Sub*Wt*Lifting_h

Task 5: Pushing and pulling at shoulder height (using force platform)

Dependent variable	Within subject variables	
1) SCM=Sternocleidomastoid N-MAV 2) TRP_C4 = upper trapezius (alnong C4) N-MAV 3) TRP_C7 = upper trapezius (alnong C7) N-MAV	Direction of force exertions (2 levels) 1) 2= pulling 2) 3 = pushing	Weights (3 levels) 1) 25% 2) 50% 3) 75%

Analysis of Variance Table for SCM

Source	DF	SS	MS	F	P
Sub	29	4240.7	146.231		
Wt	2	81.36	40.678	5.38	0.00720
Error	Sub*Wt	58	438.22	7.556	
FD	1	5.14	5.14	3.2	0.08430
Error	Sub*FD	29	46.65	1.609	
Wt*FD	2	0.93	0.465	0.19	0.82370
Error	Sub*Wt*FD	58	138.54	2.389	
Total	179	4951.53			
Grand	Mean	5.8205			
	CV(Sub*Wt)	47.23			
	CV(Sub*FD)	21.79			
	CV(Sub*Wt*FD)	26.55			

Analysis of Variance Table for TRP_C4

Source	DF	SS	MS	F	P
Sub	29	3062.11	105.59		
Wt	2	71.11	35.557	9.53	0.00030
Error	Sub*Wt	58	216.49	3.733	
FD	1	84.14	84.141	13.15	0.00110
Error	Sub*FD	29	185.53	6.398	
Wt*FD	2	3.28	1.641	0.61	0.54750
Error	Sub*Wt*FD	58	156.38	2.696	
Total	179	3779.05			
Grand	Mean	8.2513			
	CV(Sub*Wt)	23.41			
	CV(Sub*FD)	30.65			
	CV(Sub*Wt*FD)	19.9			

Analysis of Variance Table for TRP_C7

Source	DF	SS	MS	F	P
Sub	29	2995.44	103.29		
Wt	2	67.94	33.97	5.33	0.00750
Error	Sub*Wt	58	369.71	6.37	
FD	1	1375.31	1375.31	27.45	0.00000
Error	Sub*FD	29	1452.8	50.1	
Wt*FD	2	26.07	13.04	2.32	0.10750
Error	Sub*Wt*FD	58	326.11	5.62	
Total	179	6613.38			
Grand	Mean	6.2647			
	CV(Sub*Wt)	40.3			
	CV(Sub*FD)	112.98			
	CV(Sub*Wt*FD)	37.85			

Tukey HSD All-Pairwise Comparisons Test of SCM for Wt*FD

Wt	FD	Mean	25,2	25,3	50,2	50,3	75,2
25	2	5.0578					
25	3	4.9229	0.1349				
50	2	6.0577	0.9999	1.1348			
50	3	5.6107	0.5529	0.6878	0.4471		
75	2	6.8529	1.7951*	1.9300*	0.7952	1.2422	
75	3	6.421	1.3632	1.4981	0.3632	0.8103	0.4319

Comparisons of means for the same level of Wt
Alpha 0.05 Standard Error for Comparison 0.3767
Critical Q Value 4.204 Critical Value for Comparison 1.1198
Error terms used: Sub*FD and Sub*Wt*FD
Comparisons of means for different levels of Wt
Alpha 0.05 Standard Error for Comparison 0.5757
Critical Q Value 4.168 Critical Value for Comparison 1.6967
Error terms used: Sub*Wt and Sub*Wt*FD

Tukey HSD All-Pairwise Comparisons Test of TRP_C4 for Wt*FD

Wt	FD	Mean	25,2	25,3	50,2	50,3	75,2
25	2	8.2583					
25	3	7.1977	1.0605				
50	2	8.5526	0.2944	1.3549			
50	3	7.2287	1.0296	0.0309	1.324		
75	2	9.9941	1.7358*	2.7963*	1.4415*	2.7654*	
75	3	8.2763	0.0181	1.0786	0.2763	1.0477	1.7178*

Comparisons of means for the same level of Wt
Alpha 0.05 Standard Error for Comparison 0.5119
Critical Q Value 4.246 Critical Value for Comparison 1.5367
Error terms used: Sub*FD and Sub*Wt*FD
Comparisons of means for different levels of Wt
Alpha 0.05 Standard Error for Comparison 0.4629
Critical Q Value 4.168 Critical Value for Comparison 1.3643
Error terms used: Sub*Wt and Sub*Wt*FD

Tukey HSD All-Pairwise Comparisons Test of TRP_C7 for Wt*FD

Wt	FD	Mean	25,2	25,3	50,2	50,3	75,2
25	2	8.147					
25	3	3.296	4.850*				
50	2	8.521	0.374	5.224*			
50	3	3.377	4.769*	0.081	5.143*		
75	2	10.419	2.272*	7.123*	1.899*	7.042*	
75	3	3.828	4.319*	0.531	4.693*	0.45	6.591*

Comparisons of means for the same level of Wt
Alpha 0.05 Standard Error for Comparison 1.1675
Critical Q Value 4.285 Critical Value for Comparison 3.5376
Error terms used: Sub*FD and Sub*Wt*FD
Comparisons of means for different levels of Wt
Alpha 0.05 Standard Error for Comparison 0.6324
Critical Q Value 4.168 Critical Value for Comparison 1.8637
Error terms used: Sub*Wt and Sub*Wt*FD

Task 6: Overhead pulling (using force platform)

Dependent variable	**Within subject variables**
1) SCM=Sternocleidomastoid N-MAV 2) TRP_C4 = upper trapezius (alnong C4) N-MAV 3) TRP_C7 = upper trapezius (alnong C7) N-MAV	Weights (3 levels) 1) 25% 2) 50% 3) 75%

Analysis of Variance Table for SCM

Source	DF	SS	MS	F	P
Sub	29	1937.5	66.8103		
Wt	2	57.91	28.9537	4.64	0.01360
Error	58	362.25	6.2456		
Total	89	2357.65			

Grand Mean 5.8038 CV 43.06

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	51.54	51.5397	9.46	0.0032
Remainder	57	310.706	5.451		

Analysis of Variance Table for TRPU

Source	DF	SS	MS	F	P
Sub	29	1346.08	46.4165		
Wt	2	4.54	2.2719	3.03	0.05610
Error	58	43.51	0.7502		
Total	89	1394.14			

Grand Mean 7.1623   CV 12.09

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	3.7802	3.78019	5.42	0.0234
Remainder	57	39.733	0.69707		

Analysis of Variance Table for TRPL

Source	DF	SS	MS	F	P
Sub	29	594.05	20.4845		
Wt	2	20.796	10.3978	2.29	0.11000
Error	58	263.005	4.5346		
Total	89	877.851			

Grand Mean 2.9017   CV 73.39

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	56.56	56.56	15.6	0.0002
Remainder	57	206.445	3.6218		

Tukey HSD All-Pairwise Comparisons Test of SCM for Wt

Wt	Mean	25	50
25	5		
50	5	0.1704	
75	7	1.7804*	1.6100*

Alpha 0.05   Standard Error for Comparison 0.6453
Critical Q Value 3.402   Critical Value for Comparison 1.5523
Error term used: Sub*Wt, 58 DF

Tukey HSD All-Pairwise Comparisons Test of TRPU for Wt

Wt	Mean	25	50
25	7		
50	7	0.2906	
75	7	0.5501*	0.2594

Alpha 0.05 Standard Error for Comparison 0.2236
Critical Q Value 3.402 Critical Value for Comparison 0.5380
Error term used: Sub*Wt, 58 DF

Tukey HSD All-Pairwise Comparisons Test of TRPL for Wt

Wt	Mean	25	50
25	3		
50	3	0.0964	
75	4	1.0645	0.9681

Alpha 0.05 Standard Error for Comparison 0.5498
Critical Q Value 3.402 Critical Value for Comparison 1.3227
Error term used: Sub*Wt, 58 DF

Effect of weights or level of exertion

Effect of weights or level of force exertion	
Forceful exertion (tasks) **(13 levels)**	**Levels of force exertion** **(3 levels)**
1) lifting at **knuckle** height in *neutral* neck posture 2) lifting at **elbow** height in *fully extended* neck posture 3) lifting at **elbow** height in *neutral* neck posture 4) lifting at **elbow** height in *fully flexed* posture 5) lifting at **shoulder** height in *fully extended* neck posture 6) lifting at **shoulder** height in *neutral* neck posture 7) lifting at **shoulder** height in *fully flexed* posture 8) lifting at **overhead** height in *fully extended* neck posture 9) lifting at **overhead** height in *neutral* neck posture 10) lifting at **overhead** height in *fully flexed* posture 11) pulling at **shoulder** height in *neutral* neck posture 12) pushing at **shoulder** height in *neutral* neck posture 13) pulling at **overhead** height in *neutral* neck posture	1) 25% 2) 50% 3) 75%

Analysis of Variance Table for SCM

Source	DF	SS	MS	F	P
Sub	29	58696	2023.99		
Wt	2	7222	3610.91	77.2	0.00000
Error	Sub*Wt	58	2713	46.78	
Task	12	87840	7320.01	30.38	0.00000
Error	Sub*Task	348	83860	240.98	
Wt*Task	24	3984	165.98	10.15	0.00000
Error	Sub*Wt*Task	696	11384	16.36	
Total	1169	255698			
Grand	Mean	11.011			
	CV(Sub*Wt)	62.11			
	CV(Sub*Task)	140.98			
	CV(Sub*Wt*Task)	36.73			

Analysis of Variance Table for TRP_C4

Source	DF	SS	MS	F	P
Sub	29	71794	2475.7		
Wt	2	37227	18613.7	81.15	0.00000
Error	Sub*Wt	58	13303	229.4	
Task	12	123551	10295.9	42.8	0.00000
Error	Sub*Task	348	83723	240.6	
Wt*Task	24	19032	793	14.84	0.00000
Error	Sub*Wt*Task	696	37195	53.4	
Total	1169	385825			
Grand	Mean	20.72			
	CV(Sub*Wt)	73.09			
	CV(Sub*Task)	74.86			
	CV(Sub*Wt*Task)	35.28			

Analysis of Variance Table for TRP_C7

Source	DF	SS	MS	F	P
Sub	29	152647	5263.7		
Wt	2	47902	23950.8	111.21	0.00000
Error	Sub*Wt	58	12491	215.4	
Task	12	247531	20627.6	65.75	0.00000
Error	Sub*Task	348	109173	313.7	
Wt*Task	24	18590	774.6	13.73	0.00000
Error	Sub*Wt*Task	696	39266	56.4	
Total	1169	627599			
Grand	Mean	24.629			
	CV(Sub*Wt)	59.59			
	CV(Sub*Task)	71.92			
	CV(Sub*Wt*Task)	30.5			

Tukey HSD All-Pairwise Comparisons Test of SCM for Wt*Task

Wt	Task	Mean	25,1	25,2	25,3	25,4	25,5	25,6	25,7	25,8	25,9	25,10
25	1	3.891										
25	2	13.446	9.555*									
25	3	3.14	0.751	10.306*								
25	4	3.461	0.43	9.985*	0.321							
25	5	20.36	16.469*	6.914	17.220*	16.899*						
25	6	4.201	0.31	9.245	1.061	0.74	16.159*					
25	7	4.648	0.757	8.798	1.508	1.187	15.712*	0.447				
25	8	24.906	21.015*	11.460*	21.766*	21.446*	4.546	20.705*	20.259*			
25	9	5.966	2.075	7.48	2.826	2.505	14.394*	1.765	1.318	18.941*		
25	10	6.386	2.495	7.06	3.246	2.925	13.974*	2.185	1.738	18.521*	0.42	
25	11	5.058	1.167	8.388	1.918	1.597	15.302*	0.856	0.41	19.849*	0.908	1.328
25	12	4.923	1.032	8.523	1.783	1.462	15.437*	0.722	0.275	19.984*	1.043	1.463
25	13	5.154	1.262	8.292	2.014	1.693	15.206*	0.952	0.506	19.753*	0.812	1.232
50	1	4.163	0.272	9.283*	1.023	0.702	16.197*	0.038	0.485	20.743*	1.803	2.223
50	2	17.515	13.624*	4.069	14.375*	14.054*	2.845	13.314*	12.868*	7.391*	11.549*	11.129*
50	3	4.188	0.297	9.258*	1.048	0.727	16.172*	0.014	0.46	20.719*	1.778	2.198
50	4	4.023	0.132	9.423*	0.883	0.562	16.337*	0.178	0.625	20.884*	1.943	2.363
50	5	24.298	20.407*	10.852*	21.158*	20.837*	3.938	20.097*	19.650*	0.608	18.332*	17.912*
50	6	6.887	2.996	6.559*	3.747	3.426	13.473*	2.686	2.239	18.019*	0.921	0.501
50	7	7.165	3.274	6.281*	4.025	3.704	13.195*	2.964	2.517	17.741*	1.199	0.779
50	8	34.232	30.341*	20.786*	31.092*	30.771*	13.872*	30.031*	29.584*	9.326*	28.266*	27.846*
50	9	10.337	6.446*	3.109	7.197*	6.876*	10.023*	6.136*	5.689*	14.569*	4.371*	3.951
50	10	9.684	5.793*	3.762	6.544*	6.223*	10.676*	5.482*	5.036*	15.223*	3.718	3.298
50	11	6.058	2.167	7.388*	2.918	2.597	14.302*	1.856	1.41	18.849*	0.092	0.328
50	12	5.611	1.72	7.835*	2.471	2.15	14.749*	1.409	0.963	19.296*	0.355	0.775
50	13	5.324	1.433	8.122*	2.184	1.863	15.036*	1.123	0.676	19.582*	0.642	1.062
75	1	5.03	1.139	8.416*	1.89	1.569	15.330*	0.829	0.382	19.877*	0.936	1.356
75	2	22.143	18.252*	8.697*	19.003*	18.682*	1.783	17.942*	17.495*	2.763	16.177*	15.757*
75	3	6.154	2.263	7.292*	3.014	2.694	14.206*	1.953	1.507	18.752*	0.189	0.232
75	4	5.885	1.994	7.561*	2.745	2.424	14.475*	1.684	1.237	19.022*	0.081	0.501
75	5	30.837	26.946*	17.391*	27.697*	27.376*	10.477*	26.636*	26.189*	5.931*	24.871*	24.451*
75	6	9.816	5.925*	3.63	6.676*	6.355*	10.544*	5.615*	5.168*	15.090*	3.85	3.43

Wt	Task	Mean	25,1	25,2	25,3	25,4	25,5	25,6	25,7	25,8	25,9	25,10
75	7	11.045	7.153*	2.401	7.905*	7.584*	9.315*	6.843*	6.397*	13.862*	5.079*	4.659*
75	8	40.456	36.565*	27.010*	37.316*	36.995*	20.096*	36.255*	35.808*	15.550*	34.490*	34.070*
75	9	16.627	12.735*	3.181	13.487*	13.166*	3.733	12.425*	11.979*	8.280*	10.661*	10.241*
75	10	16.198	12.307*	2.752	13.058*	12.737*	4.162	11.997*	11.550*	8.708*	10.232*	9.812*
75	11	6.853	2.962	6.593*	3.713	3.392	13.507*	2.652	2.205	18.054*	0.887	0.467
75	12	6.421	2.53	7.025*	3.281	2.96	13.939*	2.22	1.773	18.485*	0.455	0.035
75	13	6.934	3.043	6.512*	3.794	3.473	13.426*	2.733	2.286	17.973*	0.968	0.548

Wt	Task	Mean	25,11	25,12	25,13
25	12	4.923	0.135		
25	13	5.154	0.096	0.231	
50	1	4.163	0.894	0.76	0.99
50	2	17.515	12.458*	12.592*	12.362*
50	3	4.188	0.87	0.735	0.966
50	4	4.023	1.035	0.9	1.131
50	5	24.298	19.241*	19.375*	19.145*
50	6	6.887	1.829	1.964	1.733
50	7	7.165	2.107	2.242	2.011
50	8	34.232	29.174*	29.309*	29.079*
50	9	10.337	5.279*	5.414*	5.183*
50	10	9.684	4.626*	4.761*	4.530*
50	11	6.058	1	1.135	0.904
50	12	5.611	0.553	0.688	0.457
50	13	5.324	0.266	0.401	0.17
75	1	5.03	0.028	0.107	0.124
75	2	22.143	17.085*	17.220*	16.990*
75	3	6.154	1.097	1.231	1.001
75	4	5.885	0.827	0.962	0.731
75	5	30.837	25.779*	25.914*	25.684*
75	6	9.816	4.758*	4.893*	4.663*
75	7	11.045	5.987*	6.122*	5.891*
75	8	40.456	35.398*	35.533*	35.303*
75	9	16.627	11.569*	11.704*	11.473*

Wt	Task	Mean	25,11	25,12
75	10	16.198	11.140*	11.275*
75	11	6.853	1.795	1.93
75	12	6.421	1.363	1.498
75	13	6.934	1.876	2.011

Wt	Task	Mean	50,1	50,2	50,3	50,4	50,5	50,6	50,7	50,8	50,9	50,10
50	1	4.163										
50	2	17.515	13.352*									
50	3	4.188	0.024	13.328*								
50	4	4.023	0.14	13.492*	0.165							
50	5	24.298	20.135*	6.783	20.111*	20.275*						
50	6	6.887	2.724	10.628*	2.699	2.864	17.411*					
50	7	7.165	3.002	10.350*	2.977	3.142	17.133*	0.278				
50	8	34.232	30.069*	16.717*	30.044*	30.209*	9.934*	27.345*	27.067*			
50	9	10.337	6.174	7.178	6.149	6.314	13.961*	3.45	3.172	23.895*		
50	10	9.684	5.52	7.832	5.496	5.661	14.615*	2.797	2.519	24.548*	0.653	
50	11	6.058	1.894	11.458*	1.87	2.035	18.241*	0.829	1.107	28.174*	4.279	3.626
50	12	5.611	1.447	11.905*	1.423	1.588	18.688*	1.276	1.554	28.621*	4.726	4.073
50	13	5.324	1.161	12.191*	1.136	1.301	18.974*	1.563	1.841	28.908*	5.013	4.36
75	1	5.03	0.867	12.485*	0.842	1.007	19.268*	1.857	2.135	29.202*	5.307*	4.654*
75	2	22.143	17.980*	4.628*	17.955*	18.120*	2.155	15.256*	14.978*	12.089*	11.806*	12.459*
75	3	6.154	1.991	11.361*	1.967	2.131	18.144*	0.733	1.011	28.078*	4.183	3.529
75	4	5.885	1.722	11.630*	1.697	1.862	18.413*	1.002	1.28	28.347*	4.452*	3.799
75	5	30.837	26.674*	13.322*	26.650*	26.814*	6.539*	23.950*	23.672*	3.395	20.500*	21.153*
75	6	9.816	5.653*	7.699*	5.628*	5.793*	14.482*	2.929	2.651	24.416*	0.521	0.132
75	7	11.045	6.881*	6.471*	6.857*	7.022*	13.254*	4.158	3.88	23.188*	0.708	1.361
75	8	40.456	36.293*	22.941*	36.269*	36.433*	16.158*	33.569*	33.291*	6.224*	30.119*	30.773*
75	9	16.627	12.463*	0.889	12.439*	12.604*	7.672*	9.740*	9.462*	17.606*	6.290*	6.943*
75	10	16.198	12.035*	1.317	12.010*	12.175*	8.100*	9.311*	9.033*	18.034*	5.861*	6.514*
75	11	6.853	2.69	10.662*	2.665	2.83	17.445*	0.034	0.312	27.379*	3.484	2.831
75	12	6.421	2.258	11.094*	2.233	2.398	17.877*	0.466	0.744	27.811*	3.916	3.263
75	13	6.934	2.771	10.581*	2.746	2.911	17.364*	0.047	0.231	27.298*	3.403	2.75

Wt	Task	Mean	50,11	50,12	50,13
50	1	4.163			
50	2	17.515			
50	3	4.188			
50	4	4.023			
50	5	24.298			
50	6	6.887			
50	7	7.165			
50	8	34.232			
50	9	10.337			
50	10	9.684			
50	11	6.058			
50	12	5.611	0.447		
50	13	5.324	0.734	0.287	
75	1	5.03	1.028	0.581	0.294
75	2	22.143	16.085*	16.532*	16.819*
75	3	6.154	0.097	0.544	0.83
75	4	5.885	0.173	0.274	0.561
75	5	30.837	24.779*	25.227*	25.513*
75	6	9.816	3.758	4.206	4.492*
75	7	11.045	4.987*	5.434*	5.721*
75	8	40.456	34.399*	34.846*	35.132*
75	9	16.627	10.569*	11.016*	11.303*
75	10	16.198	10.140*	10.587*	10.874*
75	11	6.853	0.795	1.242	1.529
75	12	6.421	0.363	0.81	1.097
75	13	6.934	0.876	1.323	1.61

Wt	Task	Mean	75,1	75,2	75,3	75,4	75,5	75,6	75,7	75,8	75,9	75,10	75,11
75	1	5.03											
75	2	22.143	17.113*										
75	3	6.154	1.124	15.989*									
75	4	5.885	0.855	16.258*	0.269								
75	5	30.837	25.807*	8.694	24.683*	24.952*							
75	6	9.816	4.786	12.327*	3.662	3.931	21.021*						
75	7	11.045	6.015	11.099*	4.89	5.16	19.793*	1.228					
75	8	40.456	35.426*	18.313*	34.302*	34.571*	9.619*	30.640*	29.412*				
75	9	16.627	11.597*	5.517	10.472*	10.742*	14.211*	6.81	5.582	23.830*			
75	10	16.198	11.168*	5.945	10.044*	10.313*	14.639*	6.382	5.154	24.258*	0.428		
75	11	6.853	1.823	15.290*	0.699	0.968	23.984*	2.963	4.192	33.603*	9.774*	9.345	
75	12	6.421	1.391	15.722*	0.267	0.536	24.416*	3.395	4.624	34.035*	10.206*	9.777*	0.432
75	13	6.934	1.904	15.209*	0.78	1.049	23.903*	2.882	4.111	33.522*	9.693*	9.264	0.081

Wt	Task	Mean	75,12
75	1	5.03	
75	2	22.143	
75	3	6.154	
75	4	5.885	
75	5	30.837	
75	6	9.816	
75	7	11.045	
75	8	40.456	
75	9	16.627	
75	10	16.198	
75	11	6.853	
75	12	6.421	
75	13	6.934	0.513

Tukey HSD All-Pairwise Comparisons Test of TRP_C4 for Wt*Task

Wt	Task	Mean	25,1	25,2	25,3	25,4	25,5	25,6	25,7	25,8	25,9	25,10
25	1	9.151										
25	2	9.53	0.379									
25	3	10.866	1.715	1.336								
25	4	14.404	5.254	4.875	3.539							
25	5	16.48	7.329	6.95	5.614	2.075						
25	6	17.914	8.763	8.384	7.048	3.509	1.434					
25	7	23.755	14.605*	14.226*	12.890*	9.351	7.276	5.842				
25	8	19.092	9.941	9.562	8.226	4.687	2.612	1.178	4.664			
25	9	17.825	8.675	8.296	6.96	3.421	1.346	0.088	5.93	1.266		
25	10	22.944	13.793*	13.414*	12.078*	8.54	6.464	5.03	0.811	3.852	5.119	
25	11	8.258	0.893	1.271	2.607	6.146	8.221	9.655	15.497*	10.834*	9.567	14.686*
25	12	7.198	1.953	2.332	3.668	7.207	9.282	10.716	16.558*	11.894*	10.628	15.746*
25	13	6.882	2.269	2.648	3.984	7.522	9.597	11.032*	16.873*	12.210*	10.943*	16.062*
50	1	10.195	1.044	0.665	0.671	4.21	6.285	7.719	13.561*	8.897*	7.631	12.749*
50	2	14.868	5.717	5.338	4.002	0.463	1.612	3.046	8.888*	4.224	2.958	8.076
50	3	15.861	6.711	6.332	4.996	1.457	0.618	2.052	7.894	3.23	1.964	7.083
50	4	18.848	9.697*	9.318*	7.982	4.444	2.369	0.934	4.907	0.244	1.023	4.096
50	5	23.723	14.572*	14.193*	12.857*	9.318*	7.243	5.809	0.033	4.631	5.897	0.779
50	6	27.557	18.407*	18.028*	16.692*	13.153*	11.078*	9.644*	3.802	8.466*	9.732*	4.613
50	7	35.55	26.399*	26.021*	24.685*	21.146*	19.071*	17.636*	11.795*	16.458*	17.725*	12.606*
50	8	26.998	17.847*	17.468*	16.132*	12.593*	10.518*	9.084*	3.242	7.906	9.172*	4.054
50	9	29.055	19.904*	19.526*	18.190*	14.651*	12.576*	11.141*	5.3	9.963*	11.230*	6.111
50	10	34.899	25.748*	25.369*	24.033*	20.494*	18.419*	16.985*	11.143*	15.807*	17.073*	11.955*
50	11	8.553	0.598	0.977	2.313	5.852	7.927	9.361*	15.203*	10.539*	9.273*	14.391*
50	12	7.229	1.922	2.301	3.637	7.176	9.251*	10.685*	16.527*	11.863*	10.597*	15.715*
50	13	7.173	1.978	2.357	3.693	7.232	9.307*	10.741*	16.583*	11.919*	10.653*	15.771*
75	1	13.463	4.312	3.933	2.597	0.942	3.017	4.451	10.292*	5.629	4.362	9.481*
75	2	20.893	11.742*	11.364*	10.027*	6.489	4.414	2.979	2.862	1.801	3.068	2.051
75	3	21.102	11.951*	11.573*	10.237*	6.698	4.623	3.188	2.653	2.01	3.277	1.842
75	4	26.404	17.254*	16.875*	15.539*	12.000*	9.925*	8.491*	2.649	7.313	8.579*	3.46
75	5	32.71	23.559*	23.181*	21.844*	18.306*	16.231*	14.796*	8.955*	13.618*	14.885*	9.766*
75	6	35.984	26.833*	26.454*	25.118*	21.580*	19.504*	18.070*	12.229*	16.892*	18.159*	13.040*

Wt	Task	Mean	25,1	25,2	25,3	25,4	25,5	25,6	25,7	25,8	25,9	25,10
75	7	50.768	41.617*	41.238*	39.902*	36.363*	34.288*	32.854*	27.012*	31.676*	32.942*	27.824*
75	8	40.133	30.982*	30.603*	29.267*	25.728*	23.653*	22.219*	16.377*	21.041*	22.307*	17.189*
75	9	42.422	33.272*	32.893*	31.557*	28.018*	25.943*	24.509*	18.667*	23.331*	24.597*	19.478*
75	10	53.682	44.531*	44.152*	42.816*	39.278*	37.202*	35.768*	29.927*	34.590*	35.857*	30.738*
75	11	9.994	0.843	0.464	0.872	4.41	6.485	7.92	13.761*	9.098*	7.831	12.950*
75	12	8.276	0.874	1.253	2.589	6.128	8.203	9.637*	15.479*	10.815*	9.549*	14.668*
75	13	7.432	1.719	2.097	3.434	6.972	9.047*	10.482*	16.323*	11.660*	10.393*	15.512*

Wt	Task	Mean	25,11	25,12	25,13
25	12	7.198	1.061		
25	13	6.882	1.376	0.316	
50	1	10.195	1.937	2.997	3.313
50	2	14.868	6.61	7.67	7.986
50	3	15.861	7.603	8.664*	8.979*
50	4	18.848	10.590*	11.650*	11.966*
50	5	23.723	15.465*	16.525*	16.841*
50	6	27.557	19.299*	20.360*	20.675*
50	7	35.55	27.292*	28.352*	28.668*
50	8	26.998	18.740*	19.800*	20.116*
50	9	29.055	20.797*	21.857*	22.173*
50	10	34.899	26.641*	27.701*	28.017*
50	11	8.553	0.294	1.355	1.671
50	12	7.229	1.03	0.031	0.347
50	13	7.173	1.086	0.025	0.291
75	1	13.463	5.205	6.265	6.581
75	2	20.893	12.635*	13.695*	14.011*
75	3	21.102	12.844*	13.904*	14.220*
75	4	26.404	18.146*	19.207*	19.522*
75	5	32.71	24.452*	25.512*	25.828*
75	6	35.984	27.726*	28.786*	29.102*
75	7	50.768	42.510*	43.570*	43.886*
75	8	40.133	31.875*	32.935*	33.251*
75	9	42.422	34.164*	35.225*	35.540*

Wt	Task	Mean	25,11	25,12	25,13
75	10	53.682	45.424*	46.484*	46.800*
75	11	9.994	1.736	2.796	3.112
75	12	8.276	0.018	1.079	1.394
75	13	7.432	0.826	0.234	0.55

Wt	Task	Mean	50,1	50,2	50,3	50,4	50,5	50,6	50,7	50,8	50,9	50,10
50	1	10.195										
50	2	14.868	4.673									
50	3	15.861	5.667	0.994								
50	4	18.848	8.653	3.98	2.987							
50	5	23.723	13.528*	8.855	7.861	4.875						
50	6	27.557	17.363*	12.690*	11.696*	8.709	3.835					
50	7	35.55	25.355*	20.682*	19.689*	16.702*	11.827*	7.993				
50	8	26.998	16.803*	12.130*	11.136*	8.15	3.275	0.56	8.552			
50	9	29.055	18.860*	14.187*	13.194*	10.207	5.332	1.498	6.495	2.057		
50	10	34.899	24.704*	20.031*	19.037*	16.051*	11.176*	7.341	0.651	7.901	5.844	
50	11	8.553	1.642	6.315	7.309	10.295	15.170*	19.005*	26.998*	18.445*	20.503*	26.346*
50	12	7.229	2.966	7.639	8.633	11.619*	16.494*	20.329*	28.322*	19.769*	21.827*	27.670*
50	13	7.173	3.022	7.695	8.689	11.675*	16.550*	20.385*	28.377*	19.825*	21.883*	27.726*
75	1	13.463	3.268	1.405	2.399	5.385	10.260*	14.095*	22.087*	13.535*	15.592*	21.436*
75	2	20.893	10.698*	6.025	5.032	2.045	2.83	6.664	14.657*	6.105	8.162	14.006*
75	3	21.102	10.907*	6.234	5.241	2.254	2.621	6.455	14.448*	5.896	7.953	13.797*
75	4	26.404	16.210*	11.537*	10.543*	7.556	2.682	1.153	9.146*	0.593	2.651	8.494*
75	5	32.71	22.515*	17.842*	16.849*	13.862*	8.987*	5.153	2.84	5.712	3.655	2.189
75	6	35.984	25.789*	21.116*	20.123*	17.136*	12.261*	8.426*	0.434	8.986*	6.929	1.085
75	7	50.768	40.573*	35.900*	34.906*	31.920*	27.045*	23.210*	15.218*	23.770*	21.713*	15.869*
75	8	40.133	29.938*	25.265*	24.271*	21.285*	16.410*	12.575*	4.583	13.135*	11.078*	5.234
75	9	42.422	32.228*	27.554*	26.561*	23.574*	18.699*	14.865*	6.872	15.425*	13.367*	7.524
75	10	53.682	43.487*	38.814*	37.821*	34.834*	29.959*	26.125*	18.132*	26.684*	24.627*	18.783*
75	11	9.994	0.201	4.874	5.867	8.854*	13.729*	17.563*	25.556*	17.004*	19.061*	24.905*
75	12	8.276	1.919	6.592	7.585	10.572*	15.447*	19.281*	27.274*	18.721*	20.779*	26.622*
75	13	7.432	2.763	7.436	8.429*	11.416*	16.291*	20.125*	28.118*	19.566*	21.623*	27.467*

Wt	Task	Mean	50,11	50,12	50,13
50	1	10.195			
50	2	14.868			
50	3	15.861			
50	4	18.848			
50	5	23.723			
50	6	27.557			
50	7	35.55			
50	8	26.998			
50	9	29.055			
50	10	34.899			
50	11	8.553			
50	12	7.229	1.324		
50	13	7.173	1.38	0.056	
75	1	13.463	4.91	6.234	6.29
75	2	20.893	12.341*	13.665*	13.720*
75	3	21.102	12.550*	13.874*	13.929*
75	4	26.404	17.852*	19.176*	19.232*
75	5	32.71	24.158*	25.481*	25.537*
75	6	35.984	27.431*	28.755*	28.811*
75	7	50.768	42.215*	43.539*	43.595*
75	8	40.133	31.580*	32.904*	32.960*
75	9	42.422	33.870*	35.194*	35.250*
75	10	53.682	45.129*	46.453*	46.509*
75	11	9.994	1.441	2.765	2.821
75	12	8.276	0.276	1.048	1.104
75	13	7.432	1.12	0.204	0.259

Wt	Task	Mean	75,1	75,2	75,3	75,4	75,5	75,6	75,7	75,8	75,9	75,10	75,11
75	1	13.463											
75	2	20.893	7.43										
75	3	21.102	7.639	0.209									
75	4	26.404	12.941*	5.511	5.302								
75	5	32.71	19.247*	11.817*	11.608*	6.306							
75	6	35.984	22.521*	15.091*	14.882*	9.58	3.274						
75	7	50.768	37.305*	29.875*	29.666*	24.363*	18.058*	14.784*					
75	8	40.133	26.670*	19.240*	19.031*	13.728*	7.423	4.149	10.635				
75	9	42.422	28.959*	21.529*	21.320*	16.018*	9.712	6.438	8.345	2.29			
75	10	53.682	40.219*	32.789*	32.580*	27.278*	20.972*	17.698*	2.914	13.549*	11.260*		
75	11	9.994	3.469	10.899*	11.108*	16.410*	22.716*	25.990*	40.774*	30.139*	32.428*	43.688*	
75	12	8.276	5.187	12.617*	12.826*	18.128*	24.434*	27.708*	42.492*	31.856*	34.146*	45.406*	1.718
75	13	7.432	6.031	13.461*	13.670*	18.972*	25.278*	28.552*	43.336*	32.701*	34.990*	46.250*	2.562

Wt	Task	Mean	75,12
75	1	13.463	
75	2	20.893	
75	3	21.102	
75	4	26.404	
75	5	32.71	
75	6	35.984	
75	7	50.768	
75	8	40.133	
75	9	42.422	
75	10	53.682	
75	11	9.994	
75	12	8.276	
75	13	7.432	0.844

Tukey HSD All-Pairwise Comparisons Test of TRP_C7 for Wt*Task

Wt	Task	Mean	25,1	25,2	25,3	25,4	25,5	25,6	25,7	25,8	25,9	25,10
25	1	7.621										
25	2	10.427	2.806									
25	3	11.486	3.864	1.059								
25	4	15.797	8.175	5.37	4.311							
25	5	23.59	15.969*	13.163*	12.105*	7.793						
25	6	24.433	16.812*	14.006*	12.948*	8.636	0.843					
25	7	29.422	21.801*	18.995*	17.937*	13.625*	5.832	4.989				
25	8	25.632	18.011*	15.205*	14.147*	9.835	2.042	1.199	3.79			
25	9	25.064	17.442*	14.636*	13.578*	9.267	1.473	0.63	4.359	0.569		
25	10	32.161	24.539*	21.734*	20.675*	16.364*	8.571	7.727	2.739	6.529	7.097	
25	11	8.147	0.525	2.28	3.339	7.65	15.443*	16.286*	21.275*	17.485*	16.917*	24.014*
25	12	3.296	4.325	7.131	8.189	12.500*	20.294*	21.137*	26.126*	22.336*	21.767*	28.864*
25	13	2.515	5.107	7.912	8.971	13.282*	21.075*	21.919*	26.907*	23.117*	22.549*	29.646*
50	1	11.133	3.512	0.706	0.352	4.664	12.457*	13.300*	18.289*	14.499*	13.930*	21.027*
50	2	18.281	10.660*	7.854	6.795	2.484	5.309	6.152	11.141*	7.351	6.782	13.880*
50	3	19.445	11.823*	9.018*	7.959	3.648	4.146	4.989	9.978*	6.188	5.619	12.716*
50	4	23.053	15.432*	12.626*	11.567*	7.256	0.537	1.38	6.369	2.579	2.011	9.108*
50	5	32.809	25.187*	22.382*	21.323*	17.012*	9.218*	8.375	3.386	7.176	7.745	0.648
50	6	36.26	28.639*	25.833*	24.774*	20.463*	12.670*	11.827*	6.838	10.628*	11.196*	4.099
50	7	43.242	35.621*	32.815*	31.756*	27.445*	19.652*	18.809*	13.820*	17.610*	18.178*	11.081*
50	8	36.166	28.545*	25.739*	24.681*	20.369*	12.576*	11.733*	6.744	10.534*	11.103*	4.006
50	9	36.423	28.802*	25.996*	24.937*	20.626*	12.833*	11.990*	7.001	10.791*	11.359*	4.262
50	10	46.314	38.693*	35.887*	34.829*	30.517*	22.724*	21.881*	16.892*	20.682*	21.251*	14.153*
50	11	8.521	0.899	1.907	2.965	7.276	15.070*	15.913*	20.902*	17.112*	16.543*	23.640*
50	12	3.377	4.244	7.05	8.108	12.419*	20.213*	21.056*	26.045*	22.255*	21.686*	28.783*
50	13	2.611	5.01	7.816	8.875*	13.186*	20.979*	21.822*	26.811*	23.021*	22.452*	29.550*
75	1	15.59	7.969	5.163	4.105	0.207	8	8.843*	13.832*	10.042*	9.473*	16.570*
75	2	24.615	16.994*	14.188*	13.130*	8.819*	1.025	0.182	4.807	1.017	0.448	7.545
75	3	25.401	17.780*	14.974*	13.916*	9.604*	1.811	0.968	4.021	0.231	0.338	6.759
75	4	32.731	25.109*	22.303*	21.245*	16.934*	9.140*	8.297	3.308	7.098	7.667	0.57
75	5	44.799	37.178*	34.372*	33.314*	29.002*	21.209*	20.366*	15.377*	19.167*	19.736*	12.638*
75	6	44.044	36.423*	33.617*	32.558*	28.247*	20.454*	19.611*	14.622*	18.412*	18.981*	11.883*

Wt	Task	Mean	25,1	25,2	25,3	25,4	25,5	25,6	25,7	25,8	25,9	25,10
75	7	57.635	50.014*	47.208*	46.149*	41.838*	34.045*	33.202*	28.213*	32.003*	32.572*	25.474*
75	8	48.864	41.243*	38.437*	37.379*	33.068*	25.274*	24.431*	19.442*	23.232*	23.801*	16.704*
75	9	50.999	43.377*	40.572*	39.513*	35.202*	27.409*	26.566*	21.577*	25.367*	25.935*	18.838*
75	10	60.79	53.169*	50.363*	49.304*	44.993*	37.200*	36.357*	31.368*	35.158*	35.727*	28.629*
75	11	10.419	2.798	0.008	1.066	5.378	13.171*	14.014*	19.003*	15.213*	14.644*	21.741*
75	12	3.828	3.794	6.599	7.658	11.969*	19.762*	20.605*	25.594*	21.804*	21.236*	28.333*
75	13	3.579	4.042	6.848	7.906	12.218*	20.011*	20.854*	25.843*	22.053*	21.484*	28.582*

Wt	Task	Mean	25,11	25,12	25,13
25	12	3.296	4.85		
25	13	2.515	5.632	0.782	
50	1	11.133	2.987	7.837	8.619*
50	2	18.281	10.134*	14.985*	15.766*
50	3	19.445	11.298*	16.148*	16.930*
50	4	23.053	14.906*	19.757*	20.538*
50	5	32.809	24.662*	29.512*	30.294*
50	6	36.26	28.113*	32.964*	33.745*
50	7	43.242	35.095*	39.946*	40.727*
50	8	36.166	28.020*	32.870*	33.652*
50	9	36.423	28.276*	33.127*	33.908*
50	10	46.314	38.167*	43.018*	43.799*
50	11	8.521	0.374	5.224	6.006
50	12	3.377	4.769	0.081	0.863
50	13	2.611	5.536	0.685	0.096
75	1	15.59	7.443	12.294*	13.076*
75	2	24.615	16.469*	21.319*	22.101*
75	3	25.401	17.255*	22.105*	22.887*
75	4	32.731	24.584*	29.434*	30.216*
75	5	44.799	36.652*	41.503*	42.284*
75	6	44.044	35.897*	40.748*	41.529*
75	7	57.635	49.488*	54.339*	55.120*
75	8	48.864	40.718*	45.568*	46.350*
75	9	50.999	42.852*	47.703*	48.484*

Wt	Task	Mean	25,11	25,12	25,13
75	10	60.79	52.643*	57.494*	58.275*
75	11	10.419	2.272	7.123	7.905
75	12	3.828	4.319	0.531	1.313
75	13	3.579	4.568	0.283	1.064

Wt	Task	Mean	50,1	50,2	50,3	50,4	50,5	50,6	50,7	50,8	50,9	50,10
50	1	11.133										
50	2	18.281	7.148									
50	3	19.445	8.311	1.164								
50	4	23.053	11.920*	4.772	3.608							
50	5	32.809	21.675*	14.528*	13.364*	9.756						
50	6	36.26	25.127*	17.979*	16.815*	13.207*	3.451					
50	7	43.242	32.109*	24.961*	23.797*	20.189*	10.433	6.982				
50	8	36.166	25.033*	17.885*	16.722*	13.113*	3.358	0.094	7.076			
50	9	36.423	25.290*	18.142*	16.978*	13.370*	3.614	0.163	6.819	0.257		
50	10	46.314	35.181*	28.033*	26.869*	23.261*	13.506*	10.054	3.072	10.148	9.891	
50	11	8.521	2.613	9.761	10.924	14.532*	24.288*	27.739*	34.721*	27.646*	27.902*	37.794*
50	12	3.377	7.756	14.904*	16.067*	19.676*	29.431*	32.883*	39.865*	32.789*	33.045*	42.937*
50	13	2.611	8.522	15.670*	16.834*	20.442*	30.197*	33.649*	40.631*	33.555*	33.812*	43.703*
75	1	15.59	4.457	2.691	3.854	7.463	17.218*	20.670*	27.652*	20.576*	20.833*	30.724*
75	2	24.615	13.482*	6.334	5.171	1.562	8.193	11.645*	18.627*	11.551*	11.807*	21.699*
75	3	25.401	14.268*	7.12	5.957	2.348	7.407	10.859*	17.841*	10.765*	11.022*	20.913*
75	4	32.731	21.597*	14.449*	13.286*	9.678*	0.078	3.529	10.511*	3.436	3.692	13.584*
75	5	44.799	33.666*	26.518*	25.355*	21.746*	11.991*	8.539*	1.557	8.633*	8.376	1.515
75	6	44.044	32.911*	25.763*	24.599*	20.991*	11.235*	7.784	0.802	7.878	7.621	2.27
75	7	57.635	46.502*	39.354*	38.190*	34.582*	24.826*	21.375*	14.393*	21.469*	21.212*	11.321*
75	8	48.864	37.731*	30.583*	29.420*	25.811*	16.056*	12.604*	5.622	12.698*	12.441*	2.55
75	9	50.999	39.866*	32.718*	31.554*	27.946*	18.190*	14.739*	7.757	14.833*	14.576*	4.685
75	10	60.79	49.657*	42.509*	41.345*	37.737*	27.981*	24.530*	17.548*	24.624*	24.367*	14.476*
75	11	10.419	0.714	7.862	9.025*	12.634*	22.389*	25.841*	32.823*	25.747*	26.004*	35.895*
75	12	3.828	7.306	14.453*	15.617*	19.225*	28.981*	32.432*	39.414*	32.339*	32.595*	42.486*
75	13	3.579	7.554	14.702*	15.865*	19.474*	29.229*	32.681*	39.663*	32.587*	32.844*	42.735*

Wt	Task	Mean	50,11	50,12	50,13
50	1	11.133			
50	2	18.281			
50	3	19.445			
50	4	23.053			
50	5	32.809			
50	6	36.26			
50	7	43.242			
50	8	36.166			
50	9	36.423			
50	10	46.314			
50	11	8.521			
50	12	3.377	5.143		
50	13	2.611	5.909	0.766	
75	1	15.59	7.07	12.213*	12.979*
75	2	24.615	16.095*	21.238*	22.004*
75	3	25.401	16.881*	22.024*	22.790*
75	4	32.731	24.210*	29.353*	30.119*
75	5	44.799	36.279*	41.422*	42.188*
75	6	44.044	35.523*	40.667*	41.433*
75	7	57.635	49.114*	54.258*	55.024*
75	8	48.864	40.344*	45.487*	46.253*
75	9	50.999	42.478*	47.621*	48.388*
75	10	60.79	52.270*	57.413*	58.179*
75	11	10.419	1.899	7.042	7.808
75	12	3.828	4.693	0.45	1.217
75	13	3.579	4.941	0.202	0.968

Wt	Task	Mean	75,1	75,2	75,3	75,4	75,5	75,6	75,7	75,8	75,9	75,10	75,11
75	1	15.59											
75	2	24.615	9.025										
75	3	25.401	9.811	0.786									
75	4	32.731	17.140*	8.115	7.329								
75	5	44.799	29.209*	20.184*	19.398*	12.069*							
75	6	44.044	28.454*	19.429*	18.643*	11.313	0.755						
75	7	57.635	42.045*	33.020*	32.234*	24.904*	12.836*	13.591*					
75	8	48.864	33.274*	24.249*	23.463*	16.134*	4.065	4.82	8.771				
75	9	50.999	35.409*	26.383*	25.598*	18.268*	6.2	6.955	6.636	2.135			
75	10	60.79	45.200*	36.175*	35.389*	28.060*	15.991*	16.746*	3.155	11.926*	9.791		
75	11	10.419	5.171	14.196*	14.982*	22.311*	34.380*	33.625*	47.216*	38.445*	40.580*	50.371*	
75	12	3.828	11.762	20.788*	21.573*	28.903*	40.971*	40.216*	53.807*	45.037*	47.171*	56.962*	6.591
75	13	3.579	12.011*	21.036*	21.822*	29.151*	41.220*	40.465*	54.056*	45.285*	47.420*	57.211*	6.84

Wt	Task	Mean	75,12
75	1	15.59	
75	2	24.615	
75	3	25.401	
75	4	32.731	
75	5	44.799	
75	6	44.044	
75	7	57.635	
75	8	48.864	
75	9	50.999	
75	10	60.79	
75	11	10.419	
75	12	3.828	
75	13	3.579	0.249

Effect of neck posture

Effect of neck posture	
Forceful exertion (tasks) **(9 levels)** 1) lifting 25% weight at **elbow** height 2) lifting 50% weight at **elbow** height 3) lifting 75% weight at **elbow** height 4) lifting 25% weight at **shoulder** height 5) lifting 50% weight at **shoulder** height 6) lifting 75% weight at **shoulder** height 7) lifting 25% weight at **overhead** height 8) lifting 50% weight at **overhead** height 9) lifting 75% weight at **overhead** height	**Neck postures** **(3 levels)** 1) fully extended 2) neutral 3) fully flexed

Analysis of Variance Table for SCM

Source	DF	SS	MS	F	P
Sub	29	61162	2109		
Neck	2	57098	28548.8	40.07	0.00000
Error	Sub*Neck	58	41318	712.4	
Task	8	22082	2760.3	24.4	0.00000
Error	Sub*Task	232	26251	113.1	
Neck*Task	16	3486	217.8	5.18	0.00000
Error	Sub*Neck*Task	464	19531	42.1	
Total	809	230927			
Grand Mean		13.482			
	CV(Sub*Neck)	197.98			
	CV(Sub*Task)	78.9			
	CV(Sub*Neck*Task)	48.12			

Analysis of Variance Table for TRP_C4

Source	DF	SS	MS	F	P
Sub	29	92575	3192.2		
Neck	2	11145	5572.5	51.78	0.00000
Error	Sub*Neck	58	6241	107.6	
Task	8	88452	11056.5	33.86	0.00000
Error	Sub*Task	232	75749	326.5	
Neck*Task	16	3299	206.2	3.99	0.00000
Error	Sub*Neck*Task	464	23951	51.6	
Total	809	301412			
Grand Mean		26.084			
	CV(Sub*Neck)	39.77			
	CV(Sub*Task)	69.27			
	CV(Sub*Neck*Task)	27.54			

Analysis of Variance Table for TRP_C7

Source	DF	SS	MS	F	P
Sub	29	190252	6560.4		
Neck	2	11565	5782.5	48.46	0.00000
Error	Sub*Neck	58	6921	119.3	
Task	8	128216	16027	47.1	0.00000
Error	Sub*Task	232	78941	340.3	
Neck*Task	16	1654	103.4	1.76	0.03330
Error	Sub*Neck*Task	464	27184	58.6	
Total	809	444734			
Grand Mean		32.588			
	CV(Sub*Neck)	33.52			
	CV(Sub*Task)	56.6			
	CV(Sub*Neck*Task)	23.49			

Tukey HSD All-Pairwise Comparisons Test of SCM for Neck*Task

Neck	Task	Mean	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9
1	1	13.446									
1	2	17.515	4.069								
1	3	22.143	8.697*	4.628							
1	4	20.36	6.914	2.845	1.783						
1	5	24.298	10.852*	6.783	2.155	3.938					
1	6	30.837	17.391*	13.322*	8.694*	10.477*	6.539				
1	7	24.906	11.460*	7.391	2.763	4.546	0.608	5.931			
1	8	34.232	20.786*	16.717*	12.089*	13.872*	9.934*	3.395	9.326*		
1	9	40.456	27.010*	22.941*	18.313*	20.096*	16.158*	9.619*	15.550*	6.224	
2	1	3.14	10.306	14.375*	19.003*	17.220*	21.158*	27.697*	21.766*	31.092*	37.316*
2	2	4.188	9.258	13.328*	17.955*	16.172*	20.111*	26.650*	20.719*	30.044*	36.269*
2	3	6.154	7.292	11.361*	15.989*	14.206*	18.144*	24.683*	18.752*	28.078*	34.302*
2	4	4.201	9.245	13.314*	17.942*	16.159*	20.097*	26.636*	20.705*	30.031*	36.255*
2	5	6.887	6.559	10.628	15.256*	13.473*	17.411*	23.950*	18.019*	27.345*	33.569*
2	6	9.816	3.63	7.699	12.327*	10.544	14.482*	21.021*	15.090*	24.416*	30.640*
2	7	5.966	7.48	11.549*	16.177*	14.394*	18.332*	24.871*	18.941*	28.266*	34.490*
2	8	10.337	3.109	7.178	11.806*	10.023	13.961*	20.500*	14.569*	23.895*	30.119*
2	9	16.627	3.181	0.889	5.517	3.733	7.672	14.211*	8.28	17.606*	23.830*
3	1	3.461	9.985	14.054*	18.682*	16.899*	20.837*	27.376*	21.446*	30.771*	36.995*
3	2	4.023	9.423	13.492*	18.120*	16.337*	20.275*	26.814*	20.884*	30.209*	36.433*
3	3	5.885	7.561	11.630*	16.258*	14.475*	18.413*	24.952*	19.022*	28.347*	34.571*
3	4	4.648	8.798	12.868*	17.495*	15.712*	19.650*	26.189*	20.259*	29.584*	35.808*
3	5	7.165	6.281	10.35	14.978*	13.195*	17.133*	23.672*	17.741*	27.067*	33.291*
3	6	11.045	2.401	6.471	11.099*	9.315	13.254*	19.793*	13.862*	23.188*	29.412*
3	7	6.386	7.06	11.129*	15.757*	13.974*	17.912*	24.451*	18.521*	27.846*	34.070*
3	8	9.684	3.762	7.832	12.459*	10.676*	14.615*	21.153*	15.223*	24.548*	30.773*
3	9	16.198	2.752	1.317	5.945	4.162	8.1	14.639*	8.708	18.034*	24.258*

Neck	Task	Mean	2,1	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9
2	1	3.14									
2	2	4.188	1.048								
2	3	6.154	3.014	1.967							
2	4	4.201	1.061	0.014	1.953						
2	5	6.887	3.747	2.699	0.733	2.686					
2	6	9.816	6.676	5.628	3.662	5.615	2.929				
2	7	5.966	2.826	1.778	0.189	1.765	0.921	3.85			
2	8	10.337	7.197	6.149	4.183	6.136	3.45	0.521	4.371		
2	9	16.627	13.487*	12.439*	10.472*	12.425*	9.740*	6.81	10.661*	6.29	
3	1	3.461	0.321	0.727	2.694	0.74	3.426	6.355	2.505	6.876	13.166*
3	2	4.023	0.883	0.165	2.131	0.178	2.864	5.793	1.943	6.314	12.604*
3	3	5.885	2.745	1.697	0.269	1.684	1.002	3.931	0.081	4.452	10.742*
3	4	4.648	1.508	0.46	1.507	0.447	2.239	5.168	1.318	5.689	11.979*
3	5	7.165	4.025	2.977	1.011	2.964	0.278	2.651	1.199	3.172	9.462
3	6	11.045	7.905	6.857	4.89	6.843	4.158	1.228	5.079	0.708	5.582
3	7	6.386	3.246	2.198	0.232	2.185	0.501	3.43	0.42	3.951	10.241
3	8	9.684	6.544	5.496	3.529	5.482	2.797	0.132	3.718	0.653	6.943
3	9	16.198	13.058*	12.010*	10.044	11.997*	9.311	6.382	10.232	5.861	0.428

Neck	Task	Mean	3,1	3,2	3,3	3,4	3,5	3,6	3,7	3,8
3	2	4.023	0.562							
3	3	5.885	2.424	1.862						
3	4	4.648	1.187	0.625	1.237					
3	5	7.165	3.704	3.142	1.28	2.517				
3	6	11.045	7.584	7.022	5.16	6.397	3.88			
3	7	6.386	2.925	2.363	0.501	1.738	0.779	4.659		
3	8	9.684	6.223	5.661	3.799	5.036	2.519	1.361	3.298	
3	9	16.198	12.737*	12.175*	10.313*	11.550*	9.033*	5.154	9.812*	6.514

Tukey HSD All-Pairwise Comparisons Test of TRP_C4 for Neck*Task

Neck	Task	Mean	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9
1	1	9.53									
1	2	14.868	5.338								
1	3	20.893	11.364	6.025							
1	4	16.48	6.95	1.612	4.414						
1	5	23.723	14.193*	8.855	2.83	7.243					
1	6	32.71	23.181*	17.842*	11.817*	16.231*	8.987				
1	7	19.092	9.562	4.224	1.801	2.612	4.631	13.618*			
1	8	26.998	17.468*	12.130*	6.105	10.518	3.275	5.712	7.906		
1	9	40.133	30.603*	25.265*	19.240*	23.653*	16.410*	7.423	21.041*	13.135*	
2	1	10.866	1.336	4.002	10.027*	5.614	12.857*	21.844*	8.226*	16.132*	29.267*
2	2	15.861	6.332	0.994	5.032	0.618	7.861*	16.849*	3.23	11.136*	24.271*
2	3	21.102	11.573*	6.234	0.209	4.623	2.621	11.608*	2.01	5.896	19.031*
2	4	17.914	8.384*	3.046	2.979	1.434	5.809	14.796*	1.178	9.084*	22.219*
2	5	27.557	18.028*	12.690*	6.664	11.078*	3.835	5.153	8.466*	0.56	12.575*
2	6	35.984	26.454*	21.116*	15.091*	19.504*	12.261*	3.274	16.892*	8.986*	4.149
2	7	17.825	8.296*	2.958	3.068	1.346	5.897	14.885*	1.266	9.172*	22.307*
2	8	29.055	19.526*	14.187*	8.162*	12.576*	5.332	3.655	9.963*	2.057	11.078*
2	9	42.422	32.893*	27.554*	21.529*	25.943*	18.699*	9.712*	23.331*	15.425*	2.29
3	1	14.404	4.875	0.463	6.489	2.075	9.318*	18.306*	4.687	12.593*	25.728*
3	2	18.848	9.318*	3.98	2.045	2.369	4.875	13.862*	0.244	8.150*	21.285*
3	3	26.404	16.875*	11.537*	5.511	9.925*	2.682	6.306	7.313	0.593	13.728*
3	4	23.755	14.226*	8.888*	2.862	7.276	0.033	8.955*	4.664	3.242	16.377*
3	5	35.55	26.021*	20.682*	14.657*	19.071*	11.827*	2.84	16.458*	8.552*	4.583
3	6	50.768	41.238*	35.900*	29.875*	34.288*	27.045*	18.058*	31.676*	23.770*	10.635*
3	7	22.944	13.414*	8.076*	2.051	6.464	0.779	9.766*	3.852	4.054	17.189*
3	8	34.899	25.369*	20.031*	14.006*	18.419*	11.176*	2.189	15.807*	7.901*	5.234
3	9	53.682	44.152*	38.814*	32.789*	37.202*	29.959*	20.972*	34.590*	26.684*	13.549*

Neck	Task	Mean	2,1	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9
2	1	10.866									
2	2	15.861	4.996								
2	3	21.102	10.237	5.241							
2	4	17.914	7.048	2.052	3.188						
2	5	27.557	16.692*	11.696*	6.455	9.644					
2	6	35.984	25.118*	20.123*	14.882*	18.070*	8.426				
2	7	17.825	6.96	1.964	3.277	0.088	9.732	18.159*			
2	8	29.055	18.190*	13.194*	7.953	11.141	1.498	6.929	11.23		
2	9	42.422	31.557*	26.561*	21.320*	24.509*	14.865*	6.438	24.597*	13.367*	
3	1	14.404	3.539	1.457	6.698	3.509	13.153*	21.580*	3.421	14.651*	28.018*
3	2	18.848	7.982*	2.987	2.254	0.934	8.709*	17.136*	1.023	10.207*	23.574*
3	3	26.404	15.539*	10.543*	5.302	8.491*	1.153	9.580*	8.579*	2.651	16.018*
3	4	23.755	12.890*	7.894*	2.653	5.842	3.802	12.229*	5.93	5.3	18.667*
3	5	35.55	24.685*	19.689*	14.448*	17.636*	7.993*	0.434	17.725*	6.495	6.872
3	6	50.768	39.902*	34.906*	29.666*	32.854*	23.210*	14.784*	32.942*	21.713*	8.345*
3	7	22.944	12.078*	7.083	1.842	5.03	4.613	13.040*	5.119	6.111	19.478*
3	8	34.899	24.033*	19.037*	13.797*	16.985*	7.341*	1.085	17.073*	5.844	7.524*
3	9	53.682	42.816*	37.821*	32.580*	35.768*	26.125*	17.698*	35.857*	24.627*	11.260*

Neck	Task	Mean	3,1	3,2	3,3	3,4	3,5	3,6	3,7	3,8
3	1	14.404								
3	2	18.848	4.444							
3	3	26.404	12.000*	7.556						
3	4	23.755	9.351	4.907	2.649					
3	5	35.55	21.146*	16.702*	9.146	11.795*				
3	6	50.768	36.363*	31.920*	24.363*	27.012*	15.218*			
3	7	22.944	8.54	4.096	3.46	0.811	12.606*	27.824*		
3	8	34.899	20.494*	16.051*	8.494	11.143	0.651	15.869*	11.955*	
3	9	53.682	39.278*	34.834*	27.278*	29.927*	18.132*	2.914	30.738*	18.783*

Tukey HSD All-Pairwise Comparisons Test of TRP_C7 for Neck*Task

Neck	Task	Mean	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9
1	1	10.427									
1	2	18.281	7.854								
1	3	24.615	14.188*	6.334							
1	4	23.59	13.163*	5.309	1.025						
1	5	32.809	22.382*	14.528*	8.193	9.218					
1	6	44.799	34.372*	26.518*	20.184*	21.209*	11.991*				
1	7	25.632	15.205*	7.351	1.017	2.042	7.176	19.167*			
1	8	36.166	25.739*	17.885*	11.551	12.576*	3.358	8.633	10.534		
1	9	48.864	38.437*	30.583*	24.249*	25.274*	16.056*	4.065	23.232*	12.698*	
2	1	11.486	1.059	6.795	13.130*	12.105*	21.323*	33.314*	14.147*	24.681*	37.379*
2	2	19.445	9.018*	1.164	5.171	4.146	13.364*	25.355*	6.188	16.722*	29.420*
2	3	25.401	14.974*	7.12	0.786	1.811	7.407	19.398*	0.231	10.765*	23.463*
2	4	24.433	14.006*	6.152	0.182	0.843	8.375*	20.366*	1.199	11.733*	24.431*
2	5	36.26	25.833*	17.979*	11.645*	12.670*	3.451	8.539*	10.628*	0.094	12.604*
2	6	44.044	33.617*	25.763*	19.429*	20.454*	11.235*	0.755	18.412*	7.878*	4.82
2	7	25.064	14.636*	6.782	0.448	1.473	7.745	19.736*	0.569	11.103*	23.801*
2	8	36.423	25.996*	18.142*	11.807*	12.833*	3.614	8.376*	10.791*	0.257	12.441*
2	9	50.999	40.572*	32.718*	26.383*	27.409*	18.190*	6.2	25.367*	14.833*	2.135
3	1	15.797	5.37	2.484	8.819*	7.793*	17.012*	29.002*	9.835*	20.369*	33.068*
3	2	23.053	12.626*	4.772	1.562	0.537	9.756*	21.746*	2.579	13.113*	25.811*
3	3	32.731	22.303*	14.449*	8.115*	9.140*	0.078	12.069*	7.098	3.436	16.134*
3	4	29.422	18.995*	11.141*	4.807	5.832	3.386	15.377*	3.79	6.744	19.442*
3	5	43.242	32.815*	24.961*	18.627*	19.652*	10.433*	1.557	17.610*	7.076	5.622
3	6	57.635	47.208*	39.354*	33.020*	34.045*	24.826*	12.836*	32.003*	21.469*	8.771*
3	7	32.161	21.734*	13.880*	7.545	8.571*	0.648	12.638*	6.529	4.006	16.704*
3	8	46.314	35.887*	28.033*	21.699*	22.724*	13.506*	1.515	20.682*	10.148*	2.55
3	9	60.79	50.363*	42.509*	36.175*	37.200*	27.981*	15.991*	35.158*	24.624*	11.926*

Neck	Task	Mean	2,1	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9
2	1	11.486									
2	2	19.445	7.959								
2	3	25.401	13.916*	5.957							
2	4	24.433	12.948*	4.989	0.968						
2	5	36.26	24.774*	16.815*	10.859	11.827*					
2	6	44.044	32.558*	24.599*	18.643*	19.611*	7.784				
2	7	25.064	13.578*	5.619	0.338	0.63	11.196	18.981*			
2	8	36.423	24.937*	16.978*	11.022	11.990*	0.163	7.621	11.359		
2	9	50.999	39.513*	31.554*	25.598*	26.566*	14.739*	6.955	25.935*	14.576*	
3	1	15.797	4.311	3.648	9.604*	8.636*	20.463*	28.247*	9.267*	20.626*	35.202*
3	2	23.053	11.567*	3.608	2.348	1.38	13.207*	20.991*	2.011	13.370*	27.946*
3	3	32.731	21.245*	13.286*	7.329	8.297*	3.529	11.313*	7.667	3.692	18.268*
3	4	29.422	17.937*	9.978*	4.021	4.989	6.838	14.622*	4.359	7.001	21.577*
3	5	43.242	31.756*	23.797*	17.841*	18.809*	6.982	0.802	18.178*	6.819	7.757
3	6	57.635	46.149*	38.190*	32.234*	33.202*	21.375*	13.591*	32.572*	21.212*	6.636
3	7	32.161	20.675*	12.716*	6.759	7.727	4.099	11.883*	7.097	4.262	18.838*
3	8	46.314	34.829*	26.869*	20.913*	21.881*	10.054*	2.27	21.251*	9.891*	4.685
3	9	60.79	49.304*	41.345*	35.389*	36.357*	24.530*	16.746*	35.727*	24.367*	9.791*

Neck	Task	Mean	3,1	3,2	3,3	3,4	3,5	3,6	3,7	3,8
3	1	15.797								
3	2	23.053	7.256							
3	3	32.731	16.934*	9.678						
3	4	29.422	13.625*	6.369	3.308					
3	5	43.242	27.445*	20.189*	10.511	13.820*				
3	6	57.635	41.838*	34.582*	24.904*	28.213*	14.393*			
3	7	32.161	16.364*	9.108	0.57	2.739	11.081	25.474*		
3	8	46.314	30.517*	23.261*	13.584*	16.892*	3.072	11.321	14.153*	
3	9	60.79	44.993*	37.737*	28.060*	31.368*	17.548*	3.155	28.629*	14.476*

<u>Effect of lifting height</u>

Effect of lifting height	
Forceful exertion at knuckle, elbow, shoulder, and overhead **(Tasks: 10 levels)** 1) lifting at **knuckle** height in *<u>neutral</u>* neck posture 2) lifting at **elbow** height in *<u>fully extended</u>* neck posture 3) lifting at **elbow** height in *<u>neutral</u>* neck posture 4) lifting at **elbow** height in *<u>fully flexed</u>* posture 5) lifting at **shoulder** height in *<u>fully extended</u>* neck posture 6) lifting at **shoulder** height in *<u>neutral</u>* neck posture 7) lifting at **shoulder** height in *<u>fully flexed</u>* posture 8) lifting at **overhead** height in *<u>fully extended</u>* neck posture 9) lifting at **overhead** height in *<u>neutral</u>* neck posture 10) lifting at **overhead** height in *<u>fully flexed</u>* posture	**Lifting weight** **(3 levels)** 1) 25% 2) 50% 3) 75%

Analysis of Variance Table for SCM

Source	DF	SS	MS	F	P
Sub	29	59283	2044.25		
Wt	2	8213	4106.36	77.91	0.00000
Error	Sub*Wt	58	3057	52.71	
Task	9	78359	8706.53	29.49	0.00000
Error	Sub*Task	261	77047	295.2	
Wt*Task	18	2853	158.47	8.19	0.00000
Error	Sub*Wt*Task	522	10101	19.35	
Total	899	238913			
Grand	Mean	12.57			
	CV(Sub*Wt)	57.76			
	CV(Sub*Task)	136.69			
	CV(Sub*Wt*Task)	35			

Analysis of Variance Table for TRP_C4

Source	DF	SS	MS	F	P
Sub	29	86745	2991.2		
Wt	2	46552	23275.9	76.97	0.00000
Error	Sub*Wt	58	17540	302.4	
Task	9	65605	7289.4	29.64	0.00000
Error	Sub*Task	261	64178	245.9	
Wt*Task	18	9629	534.9	8.58	0.00000
Error	Sub*Wt*Task	522	32541	62.3	
Total	899	322790			
Grand	Mean	24.569			
	CV(Sub*Wt)	70.78			
	CV(Sub*Task)	63.82			
	CV(Sub*Wt*Task)	32.14			

Analysis of Variance Table for TRP_C7

Source	DF	SS	MS	F	P
Sub	29	180909	6238.2		
Wt	2	59913	29956.7	105.88	0.00000
Error	Sub*Wt	58	16411	282.9	
Task	9	112214	12468.2	42.89	0.00000
Error	Sub*Task	261	75869	290.7	
Wt*Task	18	6463	359.1	5.45	0.00000
Error	Sub*Wt*Task	522	34387	65.9	
Total	899	486166			
Grand	Mean	30.474			
	CV(Sub*Wt)	55.2			
	CV(Sub*Task)	55.95			
	CV(Sub*Wt*Task)	26.63			

Tukey HSD All-Pairwise Comparisons Test of SCM for Wt*Task

Wt	Task	Mean	25,1	25,2	25,3	25,4	25,5	25,6	25,7	25,8	25,9	25,10
25	1	3.891										
25	2	13.446	9.555									
25	3	3.14	0.751	10.306*								
25	4	3.461	0.43	9.985	0.321							
25	5	20.36	16.469*	6.914	17.220*	16.899*						
25	6	4.201	0.31	9.245	1.061	0.74	16.159*					
25	7	4.648	0.757	8.798	1.508	1.187	15.712*	0.447				
25	8	24.906	21.015*	11.460*	21.766*	21.446*	4.546	20.705*	20.259*			
25	9	5.966	2.075	7.48	2.826	2.505	14.394*	1.765	1.318	18.941*		
25	10	6.386	2.495	7.06	3.246	2.925	13.974*	2.185	1.738	18.521*	0.42	
50	1	4.163	0.272	9.283*	1.023	0.702	16.197*	0.038	0.485	20.743*	1.803	2.223
50	2	17.515	13.624*	4.069	14.375*	14.054*	2.845	13.314*	12.868*	7.391*	11.549*	11.129*
50	3	4.188	0.297	9.258*	1.048	0.727	16.172*	0.014	0.46	20.719*	1.778	2.198
50	4	4.023	0.132	9.423*	0.883	0.562	16.337*	0.178	0.625	20.884*	1.943	2.363
50	5	24.298	20.407*	10.852*	21.158*	20.837*	3.938	20.097*	19.650*	0.608	18.332*	17.912*
50	6	6.887	2.996	6.559*	3.747	3.426	13.473*	2.686	2.239	18.019*	0.921	0.501
50	7	7.165	3.274	6.281*	4.025	3.704	13.195*	2.964	2.517	17.741*	1.199	0.779
50	8	34.232	30.341*	20.786*	31.092*	30.771*	13.872*	30.031*	29.584*	9.326*	28.266*	27.846*
50	9	10.337	6.446*	3.109	7.197*	6.876*	10.023*	6.136*	5.689*	14.569*	4.371	3.951
50	10	9.684	5.793*	3.762	6.544*	6.223*	10.676*	5.482*	5.036*	15.223*	3.718	3.298
75	1	5.03	1.139	8.416*	1.89	1.569	15.330*	0.829	0.382	19.877*	0.936	1.356
75	2	22.143	18.252*	8.697*	19.003*	18.682*	1.783	17.942*	17.495*	2.763	16.177*	15.757*
75	3	6.154	2.263	7.292*	3.014	2.694	14.206*	1.953	1.507	18.752*	0.189	0.232
75	4	5.885	1.994	7.561*	2.745	2.424	14.475*	1.684	1.237	19.022*	0.081	0.501
75	5	30.837	26.946*	17.391*	27.697*	27.376*	10.477*	26.636*	26.189*	5.931*	24.871*	24.451*
75	6	9.816	5.925*	3.63	6.676*	6.355*	10.544*	5.615*	5.168*	15.090*	3.85	3.43
75	7	11.045	7.153*	2.401	7.905*	7.584*	9.315*	6.843*	6.397*	13.862*	5.079*	4.659
75	8	40.456	36.565*	27.010*	37.316*	36.995*	20.096*	36.255*	35.808*	15.550*	34.490*	34.070*
75	9	16.627	12.735*	3.181	13.487*	13.166*	3.733	12.425*	11.979*	8.280*	10.661*	10.241*
75	10	16.198	12.307*	2.752	13.058*	12.737*	4.162	11.997*	11.550*	8.708*	10.232*	9.812*

Wt	Task	Mean	50,1	50,2	50,3	50,4	50,5	50,6	50,7	50,8	50,9	50,10
50	1	4.163										
50	2	17.515	13.352*									
50	3	4.188	0.024	13.328*								
50	4	4.023	0.14	13.492*	0.165							
50	5	24.298	20.135*	6.783	20.111*	20.275*						
50	6	6.887	2.724	10.628*	2.699	2.864	17.411*					
50	7	7.165	3.002	10.350*	2.977	3.142	17.133*	0.278				
50	8	34.232	30.069*	16.717*	30.044*	30.209*	9.934	27.345*	27.067*			
50	9	10.337	6.174	7.178	6.149	6.314	13.961*	3.45	3.172	23.895*		
50	10	9.684	5.52	7.832	5.496	5.661	14.615*	2.797	2.519	24.548*	0.653	
75	1	5.03	0.867	12.485*	0.842	1.007	19.268*	1.857	2.135	29.202*	5.307*	4.654
75	2	22.143	17.980*	4.628	17.955*	18.120*	2.155	15.256*	14.978*	12.089*	11.806*	12.459*
75	3	6.154	1.991	11.361*	1.967	2.131	18.144*	0.733	1.011	28.078*	4.183	3.529
75	4	5.885	1.722	11.630*	1.697	1.862	18.413*	1.002	1.28	28.347*	4.452	3.799
75	5	30.837	26.674*	13.322*	26.650*	26.814*	6.539*	23.950*	23.672*	3.395	20.500*	21.153*
75	6	9.816	5.653*	7.699*	5.628*	5.793*	14.482*	2.929	2.651	24.416*	0.521	0.132
75	7	11.045	6.881*	6.471*	6.857*	7.022*	13.254*	4.158	3.88	23.188*	0.708	1.361
75	8	40.456	36.293*	22.941*	36.269*	36.433*	16.158*	33.569*	33.291*	6.224*	30.119*	30.773*
75	9	16.627	12.463*	0.889	12.439*	12.604*	7.672*	9.740*	9.462*	17.606*	6.290*	6.943*
75	10	16.198	12.035*	1.317	12.010*	12.175*	8.100*	9.311*	9.033*	18.034*	5.861*	6.514*

Wt	Task	Mean	75,1	75,2	75,3	75,4	75,5	75,6	75,7	75,8	75,9
75	1	5.03									
75	2	22.143	17.113*								
75	3	6.154	1.124	15.989*							
75	4	5.885	0.855	16.258*	0.269						
75	5	30.837	25.807*	8.694	24.683*	24.952*					
75	6	9.816	4.786	12.327*	3.662	3.931	21.021*				
75	7	11.045	6.015	11.099*	4.89	5.16	19.793*	1.228			
75	8	40.456	35.426*	18.313*	34.302*	34.571*	9.619	30.640*	29.412*		
75	9	16.627	11.597*	5.517	10.472*	10.742*	14.211*	6.81	5.582	23.830*	
75	10	16.198	11.168*	5.945	10.044	10.313*	14.639*	6.382	5.154	24.258*	0.428

Tukey HSD All-Pairwise Comparisons Test of TRP_C4 for Wt*Task

Wt	Task	Mean	25,1	25,2	25,3	25,4	25,5	25,6	25,7	25,8	25,9	25,10
25	1	9.151										
25	2	9.53	0.379									
25	3	10.866	1.715	1.336								
25	4	14.404	5.254	4.875	3.539							
25	5	16.48	7.329	6.95	5.614	2.075						
25	6	17.914	8.763	8.384	7.048	3.509	1.434					
25	7	23.755	14.605*	14.226*	12.890*	9.351	7.276	5.842				
25	8	19.092	9.941	9.562	8.226	4.687	2.612	1.178	4.664			
25	9	17.825	8.675	8.296	6.96	3.421	1.346	0.088	5.93	1.266		
25	10	22.944	13.793*	13.414*	12.078*	8.54	6.464	5.03	0.811	3.852	5.119	
50	1	10.195	1.044	0.665	0.671	4.21	6.285	7.719	13.561*	8.897	7.631	12.749*
50	2	14.868	5.717	5.338	4.002	0.463	1.612	3.046	8.888	4.224	2.958	8.076
50	3	15.861	6.711	6.332	4.996	1.457	0.618	2.052	7.894	3.23	1.964	7.083
50	4	18.848	9.697*	9.318*	7.982	4.444	2.369	0.934	4.907	0.244	1.023	4.096
50	5	23.723	14.572*	14.193*	12.857*	9.318*	7.243	5.809	0.033	4.631	5.897	0.779
50	6	27.557	18.407*	18.028*	16.692*	13.153*	11.078*	9.644*	3.802	8.466	9.732*	4.613
50	7	35.55	26.399*	26.021*	24.685*	21.146*	19.071*	17.636*	11.795*	16.458*	17.725*	12.606*
50	8	26.998	17.847*	17.468*	16.132*	12.593*	10.518*	9.084	3.242	7.906	9.172*	4.054
50	9	29.055	19.904*	19.526*	18.190*	14.651*	12.576*	11.141*	5.3	9.963*	11.230*	6.111
50	10	34.899	25.748*	25.369*	24.033*	20.494*	18.419*	16.985*	11.143*	15.807*	17.073*	11.955*
75	1	13.463	4.312	3.933	2.597	0.942	3.017	4.451	10.292*	5.629	4.362	9.481*
75	2	20.893	11.742*	11.364*	10.027*	6.489	4.414	2.979	2.862	1.801	3.068	2.051
75	3	21.102	11.951*	11.573*	10.237*	6.698	4.623	3.188	2.653	2.01	3.277	1.842
75	4	26.404	17.254*	16.875*	15.539*	12.000*	9.925*	8.491	2.649	7.313	8.579	3.46
75	5	32.71	23.559*	23.181*	21.844*	18.306*	16.231*	14.796*	8.955	13.618*	14.885*	9.766*
75	6	35.984	26.833*	26.454*	25.118*	21.580*	19.504*	18.070*	12.229*	16.892*	18.159*	13.040*
75	7	50.768	41.617*	41.238*	39.902*	36.363*	34.288*	32.854*	27.012*	31.676*	32.942*	27.824*
75	8	40.133	30.982*	30.603*	29.267*	25.728*	23.653*	22.219*	16.377*	21.041*	22.307*	17.189*
75	9	42.422	33.272*	32.893*	31.557*	28.018*	25.943*	24.509*	18.667*	23.331*	24.597*	19.478*
75	10	53.682	44.531*	44.152*	42.816*	39.278*	37.202*	35.768*	29.927*	34.590*	35.857*	30.738*

Wt	Task	Mean	50,1	50,2	50,3	50,4	50,5	50,6	50,7	50,8	50,9	50,10
50	1	10.195										
50	2	14.868	4.673									
50	3	15.861	5.667	0.994								
50	4	18.848	8.653	3.98	2.987							
50	5	23.723	13.528*	8.855	7.861	4.875						
50	6	27.557	17.363*	12.690*	11.696*	8.709	3.835					
50	7	35.55	25.355*	20.682*	19.689*	16.702*	11.827*	7.993				
50	8	26.998	16.803*	12.130*	11.136*	8.15	3.275	0.56	8.552			
50	9	29.055	18.860*	14.187*	13.194*	10.207	5.332	1.498	6.495	2.057		
50	10	34.899	24.704*	20.031*	19.037*	16.051*	11.176*	7.341	0.651	7.901	5.844	
75	1	13.463	3.268	1.405	2.399	5.385	10.260*	14.095*	22.087*	13.535*	15.592*	21.436*
75	2	20.893	10.698*	6.025	5.032	2.045	2.83	6.664	14.657*	6.105	8.162	14.006*
75	3	21.102	10.907*	6.234	5.241	2.254	2.621	6.455	14.448*	5.896	7.953	13.797*
75	4	26.404	16.210*	11.537*	10.543*	7.556	2.682	1.153	9.146	0.593	2.651	8.494
75	5	32.71	22.515*	17.842*	16.849*	13.862*	8.987	5.153	2.84	5.712	3.655	2.189
75	6	35.984	25.789*	21.116*	20.123*	17.136*	12.261*	8.426	0.434	8.986	6.929	1.085
75	7	50.768	40.573*	35.900*	34.906*	31.920*	27.045*	23.210*	15.218*	23.770*	21.713*	15.869*
75	8	40.133	29.938*	25.265*	24.271*	21.285*	16.410*	12.575*	4.583	13.135*	11.078*	5.234
75	9	42.422	32.228*	27.554*	26.561*	23.574*	18.699*	14.865*	6.872	15.425*	13.367*	7.524
75	10	53.682	43.487*	38.814*	37.821*	34.834*	29.959*	26.125*	18.132*	26.684*	24.627*	18.783*

Wt	Task	Mean	75,1	75,2	75,3	75,4	75,5	75,6	75,7	75,8	75,9
75	1	13.463									
75	2	20.893	7.43								
75	3	21.102	7.639	0.209							
75	4	26.404	12.941*	5.511	5.302						
75	5	32.71	19.247*	11.817*	11.608*	6.306					
75	6	35.984	22.521*	15.091*	14.882*	9.58	3.274				
75	7	50.768	37.305*	29.875*	29.666*	24.363*	18.058*	14.784*			
75	8	40.133	26.670*	19.240*	19.031*	13.728*	7.423	4.149	10.635		
75	9	42.422	28.959*	21.529*	21.320*	16.018*	9.712	6.438	8.345	2.29	
75	10	53.682	40.219*	32.789*	32.580*	27.278*	20.972*	17.698*	2.914	13.549*	11.260*

Tukey HSD All-Pairwise Comparisons Test of TRP_C7 for Wt*Task

Wt	Task	Mean	25,1	25,2	25,3	25,4	25,5	25,6	25,7	25,8	25,9	25,10
25	1	7.621										
25	2	10.427	2.806									
25	3	11.486	3.864	1.059								
25	4	15.797	8.175	5.37	4.311							
25	5	23.59	15.969*	13.163*	12.105*	7.793						
25	6	24.433	16.812*	14.006*	12.948*	8.636	0.843					
25	7	29.422	21.801*	18.995*	17.937*	13.625*	5.832	4.989				
25	8	25.632	18.011*	15.205*	14.147*	9.835	2.042	1.199	3.79			
25	9	25.064	17.442*	14.636*	13.578*	9.267	1.473	0.63	4.359	0.569		
25	10	32.161	24.539*	21.734*	20.675*	16.364*	8.571	7.727	2.739	6.529	7.097	
50	1	11.133	3.512	0.706	0.352	4.664	12.457*	13.300*	18.289*	14.499*	13.930*	21.027*
50	2	18.281	10.660*	7.854	6.795	2.484	5.309	6.152	11.141*	7.351	6.782	13.880*
50	3	19.445	11.823*	9.018	7.959	3.648	4.146	4.989	9.978*	6.188	5.619	12.716*
50	4	23.053	15.432*	12.626*	11.567*	7.256	0.537	1.38	6.369	2.579	2.011	9.108
50	5	32.809	25.187*	22.382*	21.323*	17.012*	9.218*	8.375	3.386	7.176	7.745	0.648
50	6	36.26	28.639*	25.833*	24.774*	20.463*	12.670*	11.827*	6.838	10.628*	11.196*	4.099
50	7	43.242	35.621*	32.815*	31.756*	27.445*	19.652*	18.809*	13.820*	17.610*	18.178*	11.081*
50	8	36.166	28.545*	25.739*	24.681*	20.369*	12.576*	11.733*	6.744	10.534*	11.103*	4.006
50	9	36.423	28.802*	25.996*	24.937*	20.626*	12.833*	11.990*	7.001	10.791*	11.359*	4.262
50	10	46.314	38.693*	35.887*	34.829*	30.517*	22.724*	21.881*	16.892*	20.682*	21.251*	14.153*
75	1	15.59	7.969	5.163	4.105	0.207	8	8.843	13.832*	10.042*	9.473*	16.570*
75	2	24.615	16.994*	14.188*	13.130*	8.819	1.025	0.182	4.807	1.017	0.448	7.545
75	3	25.401	17.780*	14.974*	13.916*	9.604*	1.811	0.968	4.021	0.231	0.338	6.759
75	4	32.731	25.109*	22.303*	21.245*	16.934*	9.14	8.297	3.308	7.098	7.667	0.57
75	5	44.799	37.178*	34.372*	33.314*	29.002*	21.209*	20.366*	15.377*	19.167*	19.736*	12.638*
75	6	44.044	36.423*	33.617*	32.558*	28.247*	20.454*	19.611*	14.622*	18.412*	18.981*	11.883*
75	7	57.635	50.014*	47.208*	46.149*	41.838*	34.045*	33.202*	28.213*	32.003*	32.572*	25.474*
75	8	48.864	41.243*	38.437*	37.379*	33.068*	25.274*	24.431*	19.442*	23.232*	23.801*	16.704*
75	9	50.999	43.377*	40.572*	39.513*	35.202*	27.409*	26.566*	21.577*	25.367*	25.935*	18.838*
75	10	60.79	53.169*	50.363*	49.304*	44.993*	37.200*	36.357*	31.368*	35.158*	35.727*	28.629*

Wt	Task	Mean	50,1	50,2	50,3	50,4	50,5	50,6	50,7	50,8	50,9	50,10
50	1	11.133										
50	2	18.281	7.148									
50	3	19.445	8.311	1.164								
50	4	23.053	11.920*	4.772	3.608							
50	5	32.809	21.675*	14.528*	13.364*	9.756						
50	6	36.26	25.127*	17.979*	16.815*	13.207*	3.451					
50	7	43.242	32.109*	24.961*	23.797*	20.189*	10.433	6.982				
50	8	36.166	25.033*	17.885*	16.722*	13.113*	3.358	0.094	7.076			
50	9	36.423	25.290*	18.142*	16.978*	13.370*	3.614	0.163	6.819	0.257		
50	10	46.314	35.181*	28.033*	26.869*	23.261*	13.506*	10.054	3.072	10.148	9.891	
75	1	15.59	4.457	2.691	3.854	7.463	17.218*	20.670*	27.652*	20.576*	20.833*	30.724*
75	2	24.615	13.482*	6.334	5.171	1.562	8.193	11.645*	18.627*	11.551*	11.807*	21.699*
75	3	25.401	14.268*	7.12	5.957	2.348	7.407	10.859*	17.841*	10.765*	11.022*	20.913*
75	4	32.731	21.597*	14.449*	13.286*	9.678*	0.078	3.529	10.511*	3.436	3.692	13.584*
75	5	44.799	33.666*	26.518*	25.355*	21.746*	11.991*	8.539	1.557	8.633	8.376	1.515
75	6	44.044	32.911*	25.763*	24.599*	20.991*	11.235*	7.784	0.802	7.878	7.621	2.27
75	7	57.635	46.502*	39.354*	38.190*	34.582*	24.826*	21.375*	14.393*	21.469*	21.212*	11.321*
75	8	48.864	37.731*	30.583*	29.420*	25.811*	16.056*	12.604*	5.622	12.698*	12.441*	2.55
75	9	50.999	39.866*	32.718*	31.554*	27.946*	18.190*	14.739*	7.757	14.833*	14.576*	4.685
75	10	60.79	49.657*	42.509*	41.345*	37.737*	27.981*	24.530*	17.548*	24.624*	24.367*	14.476*

Wt	Task	Mean	75,1	75,2	75,3	75,4	75,5	75,6	75,7	75,8	75,9
75	1	15.59									
75	2	24.615	9.025								
75	3	25.401	9.811	0.786							
75	4	32.731	17.140*	8.115	7.329						
75	5	44.799	29.209*	20.184*	19.398*	12.069*					
75	6	44.044	28.454*	19.429*	18.643*	11.313	0.755				
75	7	57.635	42.045*	33.020*	32.234*	24.904*	12.836*	13.591*			
75	8	48.864	33.274*	24.249*	23.463*	16.134*	4.065	4.82	8.771		
75	9	50.999	35.409*	26.383*	25.598*	18.268*	6.2	6.955	6.636	2.135	
75	10	60.79	45.200*	36.175*	35.389*	28.060*	15.991*	16.746*	3.155	11.926*	9.791

Effect of direction of force application

Analysis of Variance Table for SCM

Source	DF	SS	MS	F	P
Sub	29	8658.8	298.581		
Wt	2	1379.7	689.869	45.59	0.00000
Error	Sub*Wt	58	877.6	15.131	
Task	4	1804.8	451.202	11.89	0.00000
Error	Sub*Task	116	4400.8	37.938	
Wt*Task	8	956.8	119.6	16.06	0.00000
Error	Sub*Wt*Task	232	1728	7.448	
Total	449	19806.6			
Grand	Mean	7.0779			
	CV(Sub*Wt)	54.96			
	CV(Sub*Task)	87.02			
	CV(Sub*Wt*Task)	38.56			

Analysis of Variance Table for TRP_C4

Source	DF	SS	MS	F	P
Sub	29	17517	604		
Wt	2	6366	3183	57.52	0.00000
Error	Sub*Wt	58	3210	55.3	
Task	4	46167	11541.7	59.54	0.00000
Error	Sub*Task	116	22485	193.8	
Wt*Task	8	7716	964.5	26.98	0.00000
Error	Sub*Wt*Task	232	8295	35.8	
Total	449	111757			
Grand	Mean	16.117			
	CV(Sub*Wt)	46.16			
	CV(Sub*Task)	86.39			
	CV(Sub*Wt*Task)	37.1			

Analysis of Variance Table for TRP_C7

Source	DF	SS	MS	F	P
Sub	29	31375	1081.9		
Wt	2	7329	3664.6	79.34	0.00000
Error	Sub*Wt	58	2679	46.2	
Task	4	106545	26636.1	94.49	0.00000
Error	Sub*Task	116	32701	281.9	
Wt*Task	8	8778	1097.2	28.46	0.00000
Error	Sub*Wt*Task	232	8944	38.6	
Total	449	198350			
Grand	Mean	17.568			
	CV(Sub*Wt)	38.69			
	CV(Sub*Task)	95.57			
	CV(Sub*Wt*Task)	35.34			

Tukey HSD All-Pairwise Comparisons Test of SCM for Wt*Task

Wt	Task	Mean	25,1	25,2	25,3	25,4	25,5	50,1	50,2	50,3	50,4	50,5	75,1
25	1	4.201											
25	2	5.966	1.765										
25	3	5.058	0.856	0.908									
25	4	4.923	0.722	1.043	0.135								
25	5	5.154	0.952	0.812	0.096	0.231							
50	1	6.887	2.686*	0.921	1.829	1.964	1.733						
50	2	10.337	6.136*	4.371*	5.279*	5.414*	5.183*	3.45					
50	3	6.058	1.856	0.092	1	1.135	0.904	0.829	4.279*				
50	4	5.611	1.409	0.355	0.553	0.688	0.457	1.276	4.726*	0.447			
50	5	5.324	1.123	0.642	0.266	0.401	0.17	1.563	5.013*	0.734	0.287		
75	1	9.816	5.615*	3.850*	4.758*	4.893*	4.663*	2.929*	0.521	3.758*	4.206*	4.492*	
75	2	16.627	12.425*	10.661*	11.569*	11.704*	11.473*	9.740*	6.290*	10.569*	11.016*	11.303*	6.810*
75	3	6.853	2.652	0.887	1.795	1.93	1.699	0.034	3.484*	0.795	1.242	1.529	2.963
75	4	6.421	2.22	0.455	1.363	1.498	1.267	0.466	3.916*	0.363	0.81	1.097	3.395
75	5	6.934	2.733*	0.968	1.876	2.011	1.78	0.047	3.403*	0.876	1.323	1.61	2.882

Wt	Task	Mean	75,2	75,3	75,4
75	3	6.853	9.774*		
75	4	6.421	10.206*	0.432	
75	5	6.934	9.693*	0.081	0.513

Comparisons of means for the same level of Wt
Alpha 0.05 Standard Error for Comparison 1.0836
Critical Q Value 4.868 Critical Value for Comparison 3.7300
Error terms used: Sub*Task and Sub*Wt*Task
Comparisons of means for different levels of Wt
Alpha 0.05 Standard Error for Comparison 0.7739
Critical Q Value 4.865 Critical Value for Comparison 2.6623
Error terms used: Sub*Wt and Sub*Wt*Task

Tukey HSD All-Pairwise Comparisons Test of TRP_C4 for Wt*Task

Wt	Task	Mean	25,1	25,2	25,3	25,4	25,5	50,1	50,2	50,3	50,4	50,5	75,1
25	1	17.914											
25	2	17.825	0.088										
25	3	8.258	9.655*	9.567*									
25	4	7.198	10.716*	10.628*	1.061								
25	5	6.882	11.032*	10.943*	1.376	0.316							
50	1	27.557	9.644*	9.732*	19.299*	20.360*	20.675*						
50	2	29.055	11.141*	11.230*	20.797*	21.857*	22.173*	1.498					
50	3	8.553	9.361*	9.273*	0.294	1.355	1.671	19.005*	20.503*				
50	4	7.229	10.685*	10.597*	1.03	0.031	0.347	20.329*	21.827*	1.324			
50	5	7.173	10.741*	10.653*	1.086	0.025	0.291	20.385*	21.883*	1.38	0.056		
75	1	35.984	18.070*	18.159*	27.726*	28.786*	29.102*	8.426*	6.929*	27.431*	28.755*	28.811*	
75	2	42.422	24.509*	24.597*	34.164*	35.225*	35.540*	14.865*	13.367*	33.870*	35.194*	35.250*	6.438
75	3	9.994	7.920*	7.831*	1.736	2.796	3.112	17.563*	19.061*	1.441	2.765	2.821	25.990*
75	4	8.276	9.637*	9.549*	0.018	1.079	1.394	19.281*	20.779*	0.276	1.048	1.104	27.708*
75	5	7.432	10.482*	10.393*	0.826	0.234	0.55	20.125*	21.623*	1.12	0.204	0.259	28.552*

Wt	Task	Mean	75,2	75,3	75,4
75	3	9.994	32.428*		
75	4	8.276	34.146*	1.718	
75	5	7.432	34.990*	2.562	0.844

Comparisons of means for the same level of Wt
Alpha 0.05 Standard Error for Comparison 2.4283
Critical Q Value 4.870 Critical Value for Comparison 8.3613
Error terms used: Sub*Task and Sub*Wt*Task
Comparisons of means for different levels of Wt
Alpha 0.05 Standard Error for Comparison 1.6263
Critical Q Value 4.853 Critical Value for Comparison 5.5803
Error terms used: Sub*Wt and Sub*Wt*Task

Tukey HSD All-Pairwise Comparisons Test of TRP_C7 for Wt*Task

Wt	Task	Mean	25,1	25,2	25,3	25,4	25,5	50,1	50,2	50,3	50,4	50,5	75,1
25	1	24.433											
25	2	25.064	0.63										
25	3	8.147	16.286*	16.917*									
25	4	3.296	21.137*	21.767*	4.85								
25	5	2.515	21.919*	22.549*	5.632	0.782							
50	1	36.26	11.827*	11.196*	28.113*	32.964*	33.745*						
50	2	36.423	11.990*	11.359*	28.276*	33.127*	33.908*	0.163					
50	3	8.521	15.913*	16.543*	0.374	5.224	6.006*	27.739*	27.902*				
50	4	3.377	21.056*	21.686*	4.769	0.081	0.863	32.883*	33.045*	5.143			
50	5	2.611	21.822*	22.452*	5.536	0.685	0.096	33.649*	33.812*	5.909	0.766		
75	1	44.044	19.611*	18.981*	35.897*	40.748*	41.529*	7.784*	7.621*	35.523*	40.667*	41.433*	
75	2	50.999	26.566*	25.935*	42.852*	47.703*	48.484*	14.739*	14.576*	42.478*	47.621*	48.388*	6.955
75	3	10.419	14.014*	14.644*	2.272	7.123*	7.905*	25.841*	26.004*	1.899	7.042*	7.808*	33.625*
75	4	3.828	20.605*	21.236*	4.319	0.531	1.313	32.432*	32.595*	4.693	0.45	1.217	40.216*
75	5	3.579	20.854*	21.484*	4.568	0.283	1.064	32.681*	32.844*	4.941	0.202	0.968	40.465*

Wt	Task	Mean	75,2	75,3	75,4
75	3	10.419	40.580*		
75	4	3.828	47.171*	6.591	
75	5	3.579	47.420*	6.84	0.249

Comparisons of means for the same level of Wt
Alpha 0.05 Standard Error for Comparison 2.8245
Critical Q Value 4.875 Critical Value for Comparison 9.7370
Error terms used: Sub*Task and Sub*Wt*Task
Comparisons of means for different levels of Wt
Alpha 0.05 Standard Error for Comparison 1.6346
Critical Q Value 4.842 Critical Value for Comparison 5.5970
Error terms used: Sub*Wt and Sub*Wt*Task

Gender difference

Analysis of Variance Table for SCM

Source	DF	SS	MS	F	P
Gender	1	9304	9303.66	5.27	0.02930
Error	Gender*Sub	28	49392	1764	
Wt	2	7222	3610.91	89.8	0.00000
Gender*Wt	2	461	230.58	5.73	0.00540
Error	Gender*Sub*Wt	56	2252	40.21	
Task	12	87840	7320.01	32.82	0.00000
Gender*Task	12	8926	743.87	3.34	0.00010
Error	Gender*Sub*Task	336	74933	223.01	
Wt*Task	24	3984	165.98	10.68	0.00000
Gender*Wt*Task	24	939	39.13	2.52	0.00010
Error	Gender*Sub*Wt*Task	672	10445	15.54	
Total	1169	255698			
Grand Mean		11.011			
	CV(Gender*Sub)	381.44			
	CV(Gender*Sub*Wt)	57.59			
	CV(Gender*Sub*Task)	135.63			
	CV(Gender*Sub*Wt*Task)	35.81			

Analysis of Variance Table for TRP_C4

Source	DF	SS	MS	F	P
Gender	1	4430	4430.5	1.84	0.18560
Error	Gender*Sub	28	67364	2405.9	
Wt	2	37227	18613.7	84.92	0.00000
Gender*Wt	2	1028	514	2.34	0.10520
Error	Gender*Sub*Wt	56	12275	219.2	
Task	12	123551	10295.9	43.3	0.00000
Gender*Task	12	3826	318.8	1.34	0.19360
Error	Gender*Sub*Task	336	79897	237.8	
Wt*Task	24	19032	793	15.22	0.00000
Gender*Wt*Task	24	2191	91.3	1.75	0.01480
Error	Gender*Sub*Wt*Task	672	35004	52.1	
Total	1169	385825			
Grand	Mean	20.72			
	CV(Gender*Sub)	236.73			
	CV(Gender*Sub*Wt)	71.45			
	CV(Gender*Sub*Task)	74.42			
	CV(Gender*Sub*Wt*Task)	34.83			

Analysis of Variance Table for TRP_C7

Source	DF	SS	MS	F	P
Gender	1	21	21.1	0	0.95080
Error	Gender*Sub	28	152626	5450.9	
Wt	2	47902	23950.8	107.66	0.00000
Gender*Wt	2	33	16.4	0.07	0.92900
Error	Gender*Sub*Wt	56	12458	222.5	
Task	12	247531	20627.6	64.96	0.00000
Gender*Task	12	2478	206.5	0.65	0.79830
Error	Gender*Sub*Task	336	106694	317.5	
Wt*Task	24	18590	774.6	14.11	0.00000
Gender*Wt*Task	24	2368	98.7	1.8	0.01140
Error	Gender*Sub*Wt*Task	672	36898	54.9	
Total	1169	627599			
Grand	Mean	24.629			
	CV(Gender*Sub)	299.77			
	CV(Gender*Sub*Wt)	60.56			
	CV(Gender*Sub*Task)	72.35			
	CV(Gender*Sub*Wt*Task)	30.09			

Tukey HSD All-Pairwise Comparisons Test of SCM for Gender*Task

Gender	Task	Mean	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9	1,10
1	1	3.086										
1	2	11.412	8.326									
1	3	3.05	0.037	8.362								
1	4	3.428	0.342	7.984	0.379							
1	5	19.054	15.968*	7.642	16.004*	15.626*						
1	6	6.143	3.057	5.269	3.094	2.715	12.911*					
1	7	6.809	3.723	4.603	3.759	3.381	12.245*	0.666				
1	8	23.017	19.931*	11.605*	19.967*	19.589*	3.963	16.874*	16.208*			
1	9	8.489	5.403	2.923	5.439	5.06	10.565	2.346	1.68	14.528*		
1	10	9.412	6.325	2.001	6.362	5.983	9.643	3.268	2.602	13.605*	0.923	
1	11	4.458	1.372	6.954	1.409	1.03	14.596*	1.685	2.351	18.559*	4.03	4.953
1	12	4.007	0.92	7.406	0.957	0.578	15.047*	2.137	2.802	19.010*	4.482	5.405
1	13	4.117	1.031	7.295	1.068	0.689	14.937*	2.026	2.692	18.900*	4.372	5.294
2	1	5.637	2.55	5.776	2.587	2.208	13.417	0.507	1.172	17.380*	2.852	3.775
2	2	23.991	20.905*	12.579	20.941*	20.562*	4.937	17.848*	17.182*	0.974	15.502*	14.579
2	3	5.938	2.852	5.474	2.889	2.51	13.116	0.205	0.871	17.079*	2.55	3.473
2	4	5.484	2.398	5.928	2.434	2.056	13.57	0.659	1.325	17.533*	3.005	3.927
2	5	31.276	28.190*	19.864*	28.227*	27.848*	12.222	25.133*	24.467*	8.259	22.787*	21.865*
2	6	7.793	4.707	3.619	4.743	4.365	11.261	1.65	0.984	15.224*	0.696	1.619
2	7	8.429	5.343	2.983	5.379	5.001	10.625	2.286	1.62	14.588	0.06	0.982
2	8	43.38	40.293*	31.967*	40.330*	39.951*	24.326*	37.236*	36.571*	20.363*	34.891*	33.968*
2	9	13.464	10.378	2.052	10.414	10.036	5.59	7.321	6.655	9.553	4.975	4.053
2	10	12.1	9.014	0.688	9.051	8.672	6.954	5.957	5.291	10.917	3.611	2.689
2	11	7.521	4.434	3.892	4.471	4.092	11.533	1.377	0.712	15.496*	0.968	1.891
2	12	7.296	4.21	4.116	4.247	3.868	11.758	1.153	0.487	15.720*	1.192	2.115
2	13	7.49	4.404	3.922	4.441	4.062	11.564	1.347	0.681	15.527*	0.998	1.921

Gender	Task	Mean	1,11	1,12	1,13
1	1	3.086			
1	2	11.412			
1	3	3.05			
1	4	3.428			
1	5	19.054			
1	6	6.143			
1	7	6.809			
1	8	23.017			
1	9	8.489			
1	10	9.412			
1	11	4.458			
1	12	4.007	0.452		
1	13	4.117	0.341	0.111	
2	1	5.637	1.178	1.63	1.519
2	2	23.991	19.533*	19.984*	19.874*
2	3	5.938	1.48	1.932	1.821
2	4	5.484	1.026	1.477	1.367
2	5	31.276	26.818*	27.270*	27.159*
2	6	7.793	3.335	3.786	3.676
2	7	8.429	3.971	4.423	4.312
2	8	43.38	38.921*	39.373*	39.262*
2	9	13.464	9.006	9.457	9.347
2	10	12.1	7.642	8.094	7.983
2	11	7.521	3.062	3.514	3.403
2	12	7.296	2.838	3.29	3.179
2	13	7.49	3.032	3.484	3.373

Tukey HSD All-Pairwise Comparisons Test of SCM for Gender*Wt

Gender	Wt	Mean	1,25	1,50	1,75	2,25	2,50
1	25	6.118					
1	50	7.795	1.676				
1	75	10.66	4.541*	2.865*			
2	25	10.118	4	2.324	0.541		
2	50	13.664	7.546	5.869	3.005	3.546*	
2	75	17.709	11.591*	9.915*	7.05	7.591*	4.045*

Biomechanical modeling

Analysis of Variance Table for SCM

Source	DF	SS	MS	F	P
Participa	29	3362.98	115.96		
Wt	2	5096.7	2548.35	277.26	0.00000
Error	58	533.1	9.19		
Total	89	8992.78			

Grand Mean 21.187 CV 14.31

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	530.771	530.771	13014.1	0.00000
Remainder	57	2.325	0.041		

Analysis of Variance Table for TRP

Source	DF	SS	MS	F	P
Participa	29	840.75	28.991		
Wt	2	1274.17	637.087	277.26	0.00000
Error	58	133.27	2.298		
Total	89	2248.19			

Grand Mean 10.593 CV 14.31

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	132.693	132.693	13014.1	0.00000
Remainder	57	0.581	0.01		

Analysis of Variance Table for LS

Source	DF	SS	MS	F	P
Participa	29	1808.54	62.36		
Wt	2	2740.89	1370.45	277.26	0.00000
Error	58	286.69	4.94		
Total	89	4836.12			

Grand Mean 15.537 CV 14.31

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	285.437	285.437	13014.1	0.00000
Remainder	57	1.25	0.022		

Analysis of Variance Table for SCM

Source	DF	SS	MS	F	P
Participa	29	2152.31	74.22		
Wt	2	3261.89	1630.94	277.26	0.00000
Error	58	341.18	5.88		
Total	89	5755.38			

Grand Mean 16.950   CV 14.31

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	339.693	339.693	13014.1	0.00000
Remainder	57	1.488	0.026		

Tukey HSD All-Pairwise Comparisons Test of Scm for Wt

Wt	Mean	25	50
25	12		
50	21	9.217*	
75	30	18.433*	9.217*

Alpha 0.05 Standard Error for Comparison 0.7828
Critical Q Value 3.402 Critical Value for Comparison 1.8832
Error term used: Participa*Wt, 58 DF

Tukey HSD All-Pairwise Comparisons Test of TRP for Wt

Wt	Mean	25	50
25	6		
50	11	4.608*	
75	15	9.217*	4.608*

Alpha 0.05 Standard Error for Comparison 0.3914
Critical Q Value 3.402 Critical Value for Comparison 0.9416
Error term used: Participa*Wt, 58 DF

Tukey HSD All-Pairwise Comparisons Test of LS for Wt

Wt	Mean	25	50
25	9		
50	16	6.759*	
75	22	13.518*	6.759*

Alpha 0.05 Standard Error for Comparison 0.5740
Critical Q Value 3.402 Critical Value for Comparison 1.3810

Error term used: Participa*Wt, 58 DF

Tukey HSD All-Pairwise Comparisons Test of SC for Wt

Wt	Mean	25	50
25	10		
50	17	7.373*	
75	24	14.746*	7.373*

Alpha 0.05 Standard Error for Comparison 0.6262
Critical Q Value 3.402 Critical Value for Comparison 1.5065
Error term used: Participa*Wt, 58 DF

APPENDIX H: BIOMECHANICAL MODELING RESULTS

Participant no.	Gender	Wt	SCM	LS	SC	TRP_C4	Participant no.	Gender	Wt	SCM	LS	SC	TRP_C4
1	Male	25	17.3	12.7	13.9	8.7	16	Female	25	8.5	6.2	6.8	4.3
1	Male	50	31.8	23.3	25.4	15.9	16	Female	50	14.5	10.6	11.6	7.3
1	Male	75	46.2	33.9	37.0	23.1	16	Female	75	20.5	15.0	16.4	10.3
2	Male	25	17.8	13.1	14.3	8.9	17	Female	25	7.0	5.2	5.6	3.5
2	Male	50	32.4	23.7	25.9	16.2	17	Female	50	11.8	8.7	9.5	5.9
2	Male	75	46.9	34.4	37.5	23.4	17	Female	75	16.6	12.2	13.3	8.3
3	Male	25	12.3	9.0	9.8	6.1	18	Female	25	8.6	6.3	6.9	4.3
3	Male	50	21.6	15.8	17.3	10.8	18	Female	50	14.3	10.5	11.4	7.1
3	Male	75	30.9	22.7	24.7	15.5	18	Female	75	20.0	14.6	16.0	10.0
4	Male	25	13.8	10.1	11.1	6.9	19	Female	25	10.1	7.4	8.0	5.0
4	Male	50	24.6	18.0	19.6	12.3	19	Female	50	17.8	13.1	14.3	8.9
4	Male	75	35.3	25.9	28.2	17.7	19	Female	75	25.6	18.8	20.5	12.8
5	Male	25	17.9	13.1	14.3	8.9	20	Female	25	7.4	5.5	6.0	3.7
5	Male	50	32.8	24.1	26.3	16.4	20	Female	50	12.2	8.9	9.7	6.1
5	Male	75	47.8	35.0	38.2	23.9	20	Female	75	16.9	12.4	13.5	8.4
6	Male	25	10.3	7.6	8.2	5.2	21	Female	25	10.3	7.6	8.3	5.2
6	Male	50	17.4	12.8	13.9	8.7	21	Female	50	18.6	13.7	14.9	9.3
6	Male	75	24.5	18.0	19.6	12.3	21	Female	75	27.0	19.8	21.6	13.5
7	Male	25	12.0	8.8	9.6	6.0	22	Female	25	9.2	6.8	7.4	4.6
7	Male	50	21.6	15.8	17.3	10.8	22	Female	50	16.2	11.9	13.0	8.1
7	Male	75	31.3	22.9	25.0	15.6	22	Female	75	23.2	17.0	18.6	11.6
8	Male	25	17.3	12.7	13.8	8.7	23	Female	25	15.2	11.1	12.2	7.6
8	Male	50	31.4	23.0	25.1	15.7	23	Female	50	27.4	20.1	21.9	13.7
8	Male	75	45.5	33.4	36.4	22.8	23	Female	75	39.6	29.1	31.7	19.8
9	Male	25	12.1	8.9	9.7	6.0	24	Female	25	13.6	10.0	10.9	6.8
9	Male	50	20.8	15.2	16.6	10.4	24	Female	50	24.5	18.0	19.6	12.2
9	Male	75	29.5	21.6	23.6	14.7	24	Female	75	35.4	26.0	28.3	17.7

Participant no.	Gender	Wt	SCM	LS	SC	TRP_C4	Participant no.	Gender	Wt	SCM	LS	SC	TRP_C4
10	Male	25	11.4	8.3	9.1	5.7	25	Female	25	11.0	8.1	8.8	5.5
10	Male	50	19.4	14.2	15.5	9.7	25	Female	50	19.4	14.2	15.5	9.7
10	Male	75	27.4	20.1	21.9	13.7	25	Female	75	27.7	20.3	22.2	13.9
11	Male	25	13.1	9.6	10.5	6.5	26	Female	25	10.9	8.0	8.7	5.5
11	Male	50	22.8	16.7	18.2	11.4	26	Female	50	18.5	13.5	14.8	9.2
11	Male	75	32.4	23.8	26.0	16.2	26	Female	75	26.0	19.0	20.8	13.0
12	Male	25	13.1	9.6	10.5	6.6	27	Female	25	10.0	7.3	8.0	5.0
12	Male	50	23.9	17.5	19.1	11.9	27	Female	50	17.5	12.8	14.0	8.8
12	Male	75	34.6	25.4	27.7	17.3	27	Female	75	25.0	18.3	20.0	12.5
13	Male	25	7.8	5.7	6.3	3.9	28	Female	25	10.9	8.0	8.8	5.5
13	Male	50	12.8	9.4	10.3	6.4	28	Female	50	19.6	14.4	15.7	9.8
13	Male	75	17.8	13.1	14.3	8.9	28	Female	75	28.3	20.8	22.7	14.2
14	Male	25	13.5	9.9	10.8	6.7	29	Female	25	9.1	6.7	7.3	4.6
14	Male	50	24.0	17.6	19.2	12.0	29	Female	50	16.3	12.0	13.1	8.2
14	Male	75	34.5	25.3	27.6	17.3	29	Female	75	23.5	17.2	18.8	11.8
15	Male	25	17.3	12.7	13.9	8.7	30	Female	25	10.1	7.4	8.1	5.1
15	Male	50	31.8	23.4	25.5	15.9	30	Female	50	17.9	13.1	14.3	8.9
15	Male	75	46.3	34.0	37.1	23.2	30	Female	75	25.7	18.8	20.5	12.8

VITA

Ashish Nimbarte was born in Nagpur, India, on 26th July 1978. Nagpur, also known as the "Orange City" for its large specialty mandarin oranges, contains the geographical center of India. During his childhood he lived in Mumbai, the financial capital of India, and attended the middle and high school. He earned his undergraduate degree from the Yashwantrao Chawhan College of Engineering (Y.C.C.E.), Nagpur, in Production Engineering in May 2000.

He joined the department of Industrial Engineering at Louisiana State University in 2001. At LSU he worked as a graduate assistant in the department of Industrial Engineering and as a graduate student worker for the Agricultural Chemistry Department. He received a Master of Science in Industrial Engineering degree in summer 2005. After finishing his master's degree he worked in Motion Lab Systems Inc., Baton Rouge, USA, for eight months. In the following year he worked as a graduate student researcher in the hand research lab at the department of Orthopedic Surgery at the University of Pittsburgh.

He rejoined the department Construction Management and Industrial Engineering (CMIE) at Louisiana State University in fall 2006 to pursue his doctorate in the interdisciplinary program in engineering science majoring in industrial engineering. He expects to receive the degree of Doctor of Philosophy in summer 2009.